

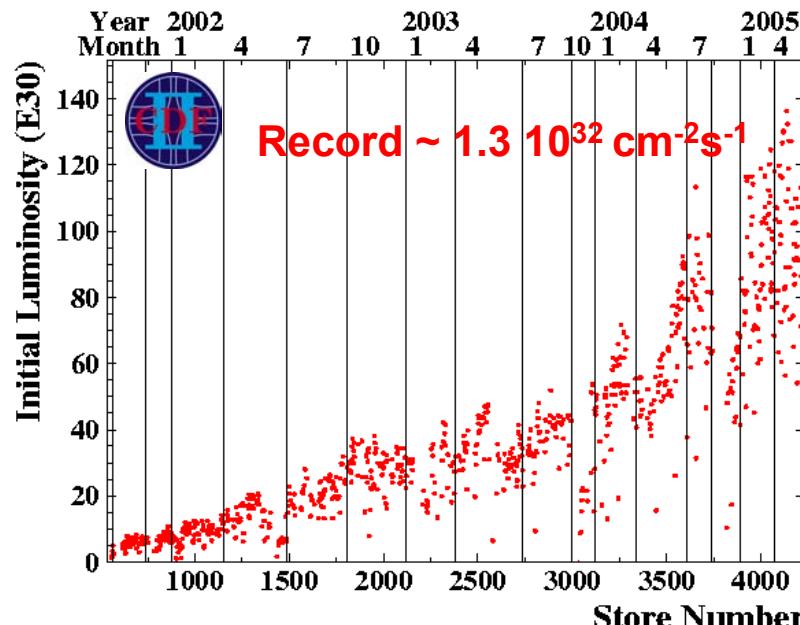
W and Z Physics



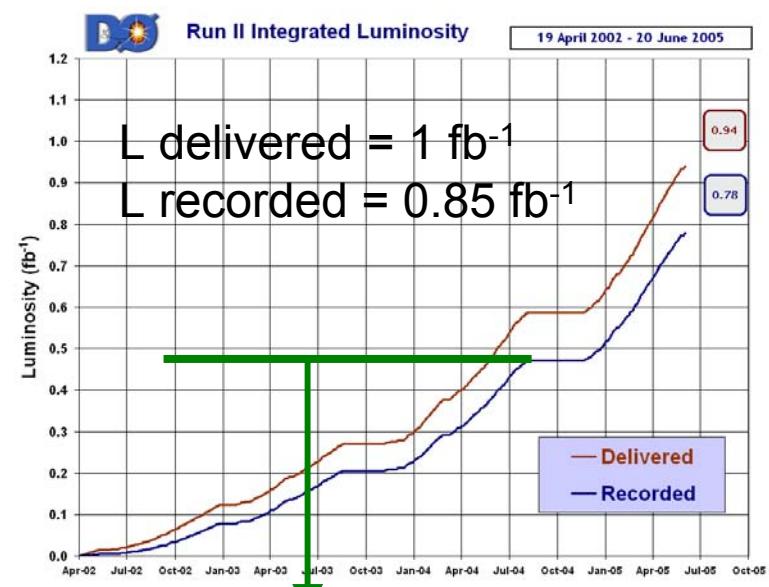
Pierre Pétroff
LAL Orsay France

PIC05
Prague
7-9 July 2005

Run II Peak Luminosity



Run II Integrated Luminosity



- Tevatron is a “boson factory” !!
rate/week with $L \sim 15 \text{ pb}^{-1}$:
 - 90.000 $W \rightarrow e/\mu$
 - 8000 $Z \rightarrow ee/\mu\mu$
 - 200 WW , 60 WZ



OUTLINE

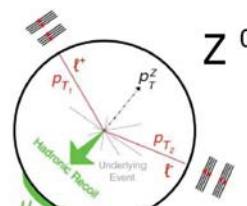
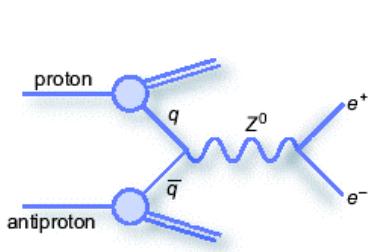


- Single boson production
 - Cross sections / W charge asymmetry/ Z/γ^* FB asymmetry
- Diboson production - WW/WZ/ $W\gamma/Z\gamma$
- Measure of W mass and W width (direct measurement)

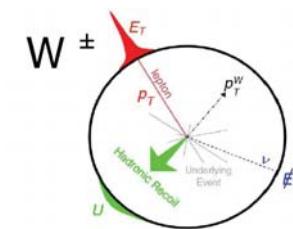
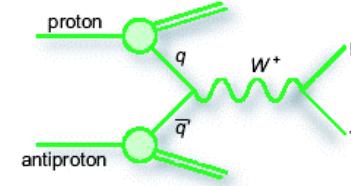
Precise EW measurements → one of the main physics goal at TeVatron
W/Z/Diboson production : important backgrounds for top, Higgs and SUSY

more information in: CDF <http://www-cdf.fnal.gov/physics/ewk/>
DØ <http://www-d0.fnal.gov/Run2Physics/WWW/results.htm>
LEP <http://lepewwg.web.cern.ch/>

- Clean, abundant and well-known signal
- Test of the Standard Model (W width, lepton universality)
- Tool to calibrate the detector and study its performances → ready for discovery !
- Can be used to cross check luminosity measurement

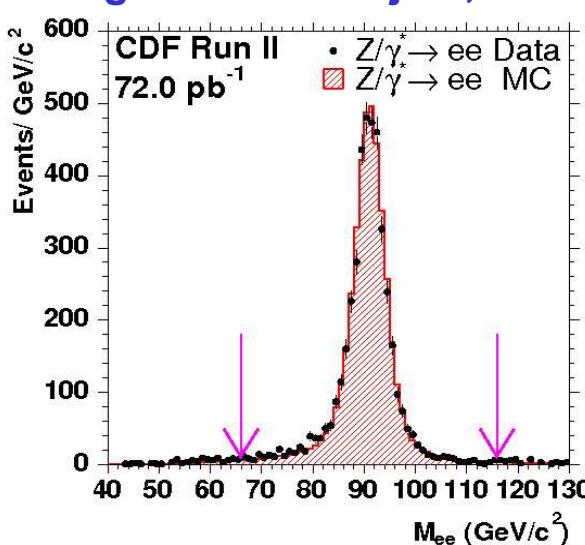


- 2 energetic leptons
- (leptons w/ opposite signs)



- energetic lepton
- missing E_T (" E_T' ")

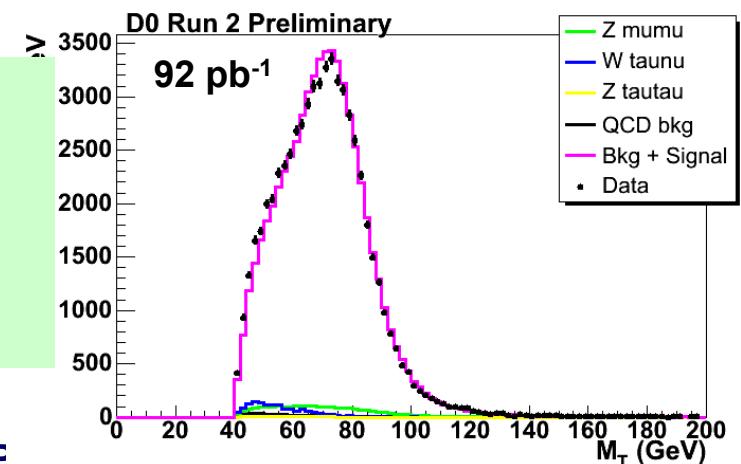
Bkgd: QCD multijets, $Z \rightarrow \tau\tau$



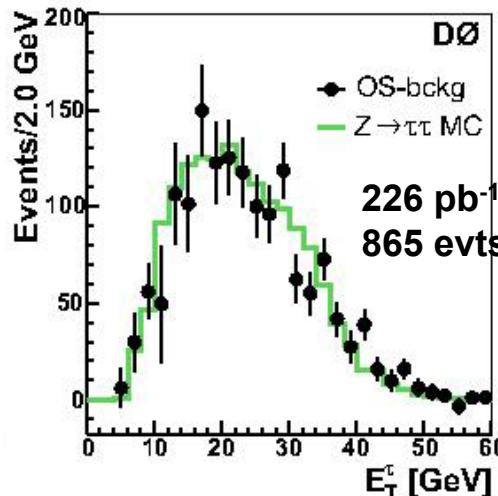
Main systematics:

- luminosity ~ 6%
- PDF (CTEQ6) → ~1-2%
- Lepton ID (~1-2%)
- Others (<1%)

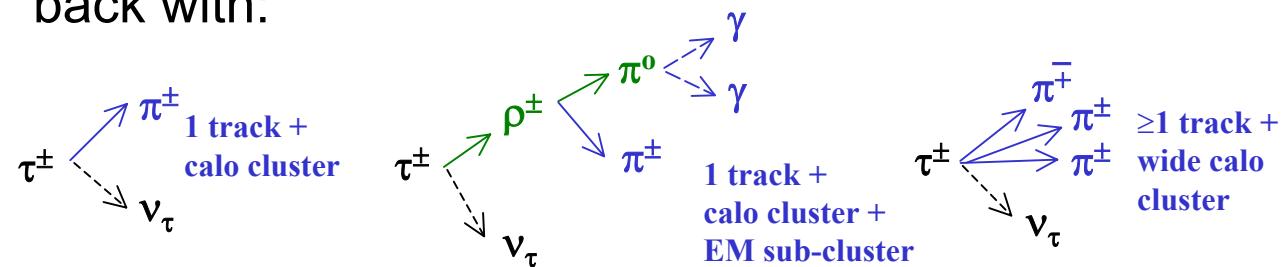
Bkgd: QCD multijet, $W \rightarrow \tau\nu$, $Z \rightarrow \tau\tau$, $Z \rightarrow ee/\mu\mu$



very important: $H \rightarrow \tau \tau$, SUSY at large $\tan\beta$
 $W/Z \rightarrow \tau$ cross-section: test the SM and ability to reconstruct τ



DØ: $Z \rightarrow \tau\tau$ with one τ decaying into muon back to back with:



τ types identified with NN technics

Main background: QCD $\sim 49\%$, $W \rightarrow \mu\nu + Z \rightarrow \mu\mu \sim 6\%$

Main systematic uncertainties: trigger = 3.5 %, QCD bkg = 3.5%

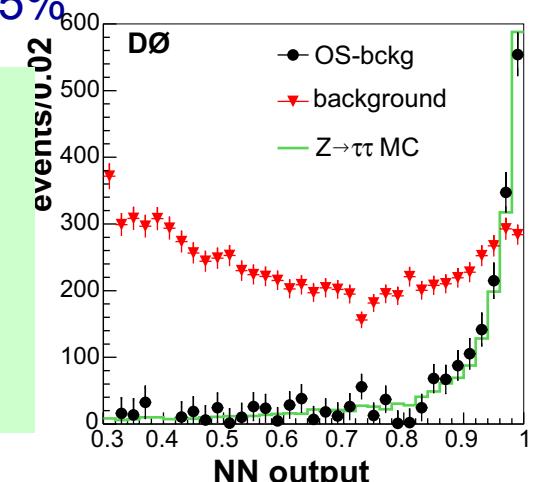
- **0.226 fb⁻¹ of data** PRD 71, 072004 (2005)

$$\sigma \cdot \text{BR}(Z/\gamma^* \rightarrow \tau^+ \tau^-) = 252 \pm 16(\text{stat}) \pm 19(\text{sys}) \text{ pb}$$

- **removing γ^* contribution yields**

$$\sigma \cdot \text{BR}(Z \rightarrow \tau^+ \tau^-) = 237 \pm 15 \text{ (stat)} \pm 18 \text{ (sys)} \pm 15 \text{ (lum)} \text{ pb}$$

- **SM expectations: 242 ± 9 pb**



CDF (72 pb⁻¹):

$$R(e+\mu) = 10.92 \pm 0.15 \text{ (stat)} \pm 0.14 \text{ (sys)}$$

DØ (177 pb⁻¹):

$$R(e) = 10.82 \pm 0.16 \text{ (stat)} \pm 0.28 \text{ (sys)}$$

CDF: $\Gamma_W = 2.079 \pm 0.041$ GeV

PRL 94, 091803

World average: $\Gamma_W = 2.124 \pm 0.041$ GeV

SM value: $\Gamma_W = 2.092 \pm 0.003$ GeV

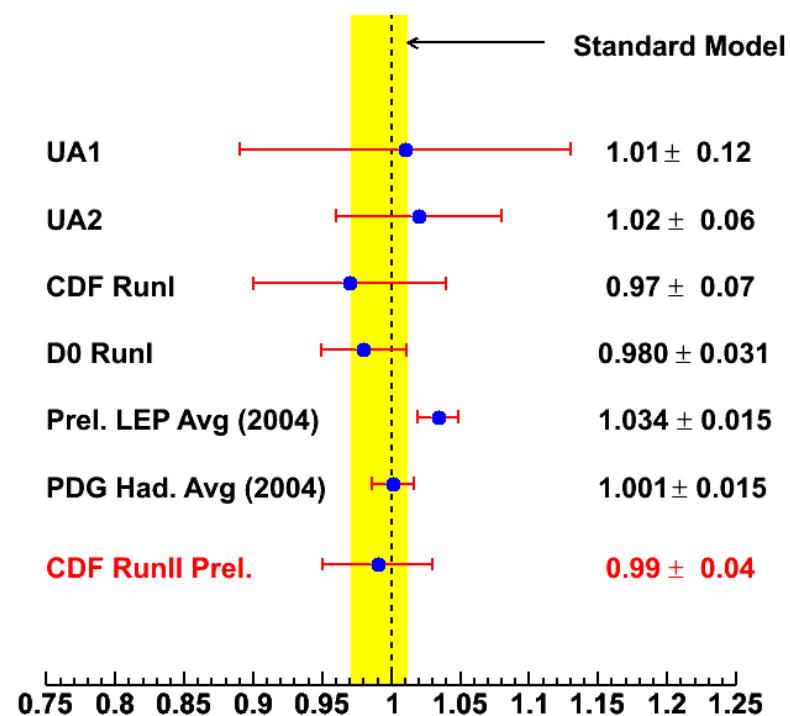
Tested by CDF with the ratio of W cross-sections

e-μ universality:

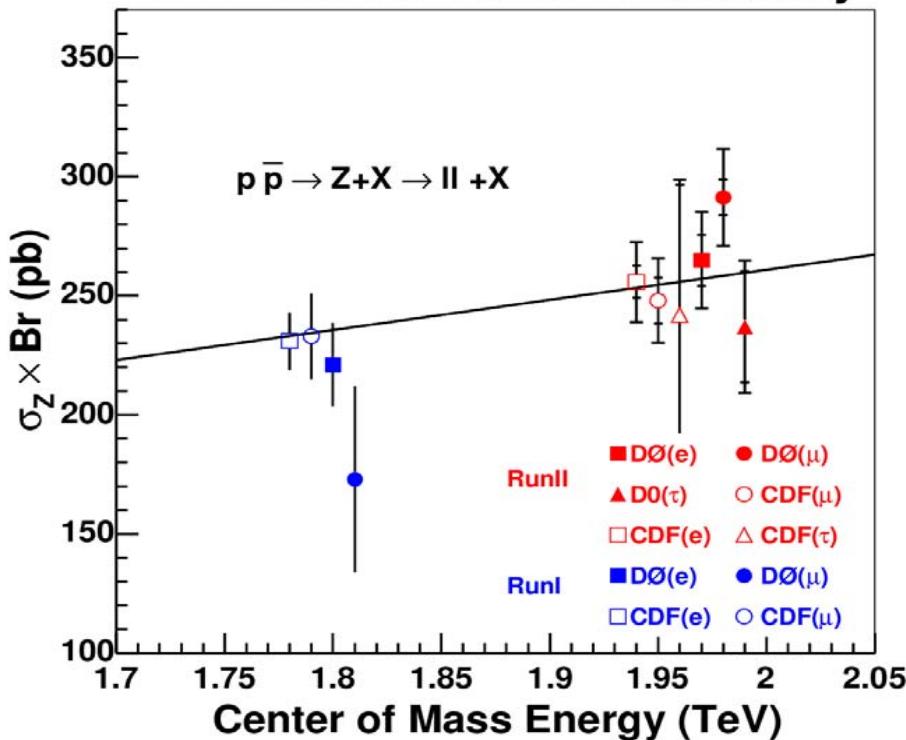
$$g_\mu/g_e = 0.998 \pm 0.004_{\text{stat}} \pm 0.011_{\text{syst}}$$

e-τ universality

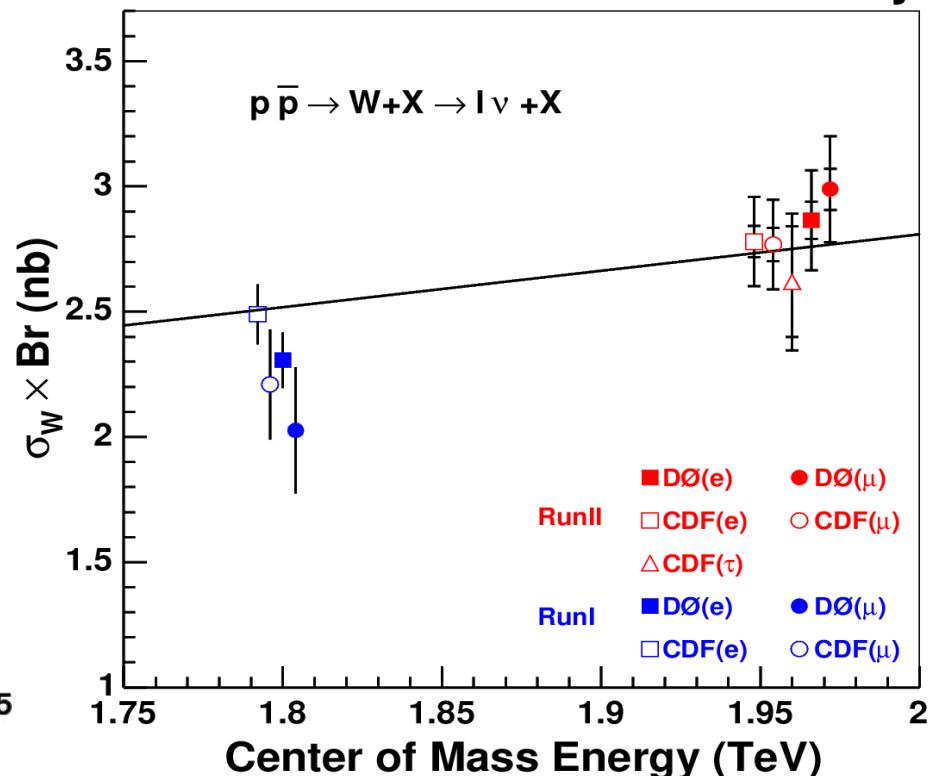
$$g_\tau/g_e = 0.99 \pm 0.02_{\text{stat}} \pm 0.04_{\text{syst}}$$



CDF and DØ RunII Preliminary



CDF and DØ Run II Preliminary



Overall good agreement with NNLO calculations:

*C.R. Hamberg, W.L. van Neerven and T. Matsuura,
Nucl. Phys. B359, 343 (1991)*

W Charge Asymmetry

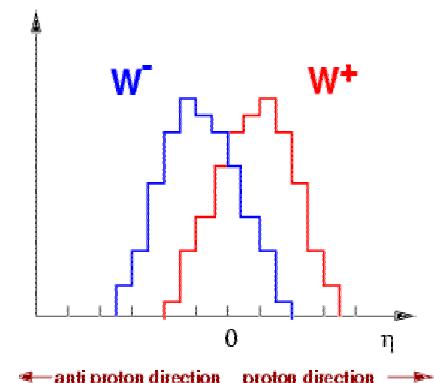
Many measurements at a hadron collider are limited by PDF uncertainties.

Forward-backward W charge asymmetry gives important input on u and d PDF.

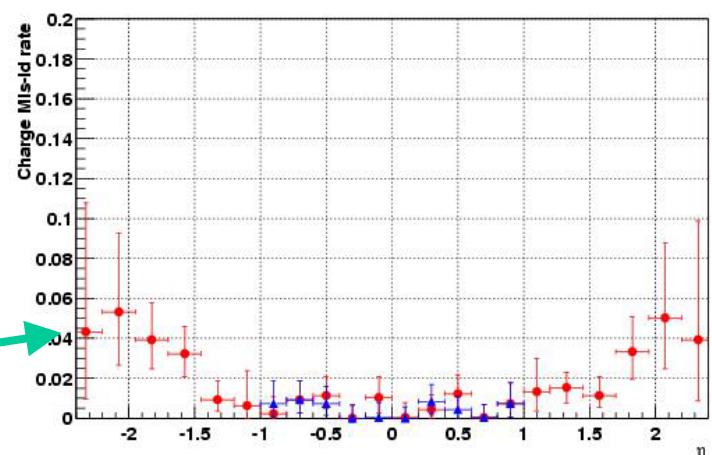
$$A(y_W) = \frac{d\sigma(W^+)/dy_W - d\sigma(W^-)/dy_W}{d\sigma(W^+)/dy_W + d\sigma(W^-)/dy_W}$$

$$x_{1(2)} = \frac{M_W}{\sqrt{s}} e^{+(-)y_W}$$

u quarks carry higher fraction of the proton momentum: $u\bar{d} \rightarrow W^+$ boosted in the proton direction



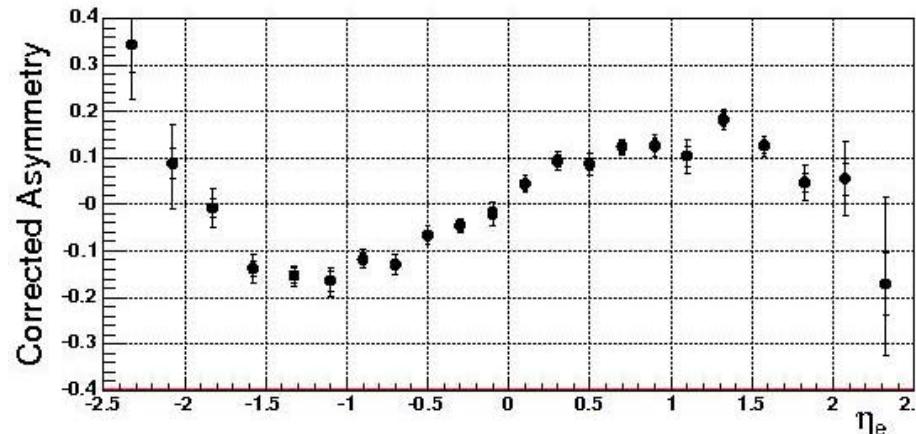
- observable quantity is $A(y_e)$:
assume SM $W \rightarrow e \nu$ coupling
→ convolution of W production asymmetry and V-A decay



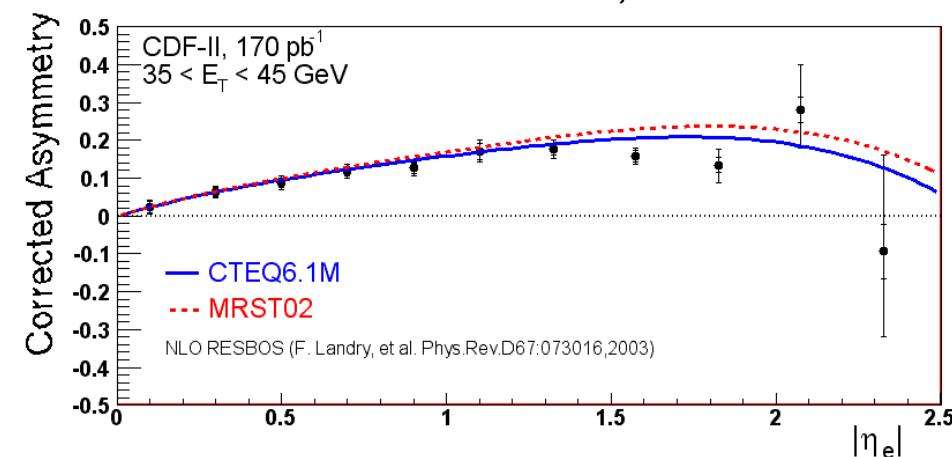
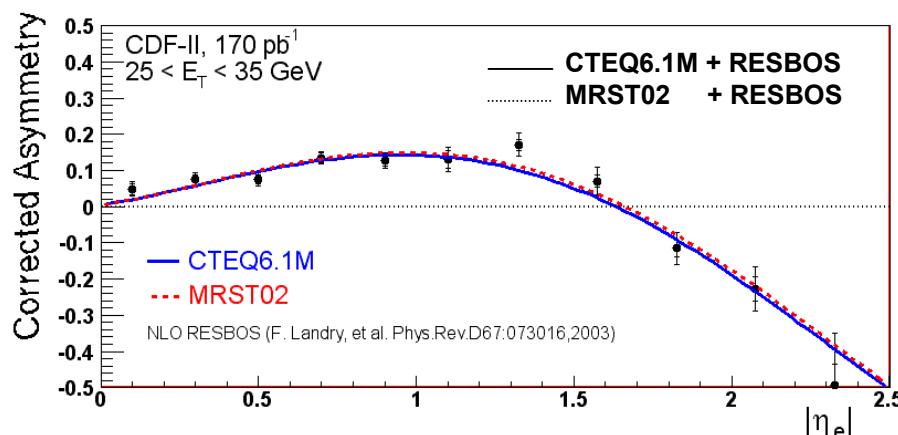
CDF measured $A(y_e)$ with 170 pb^{-1} :
77930 $W \rightarrow e\nu$, $E_T(e) > 25 \text{ GeV}$, $E_T > 25 \text{ GeV}$
 Key: lepton charge misID $\sim 4\%$ at $|\eta| \sim 2$

No CP asymmetry

CDF



PRD 71,051104



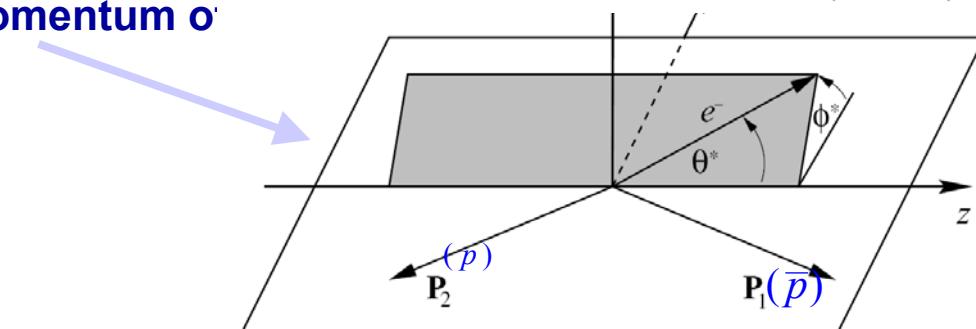
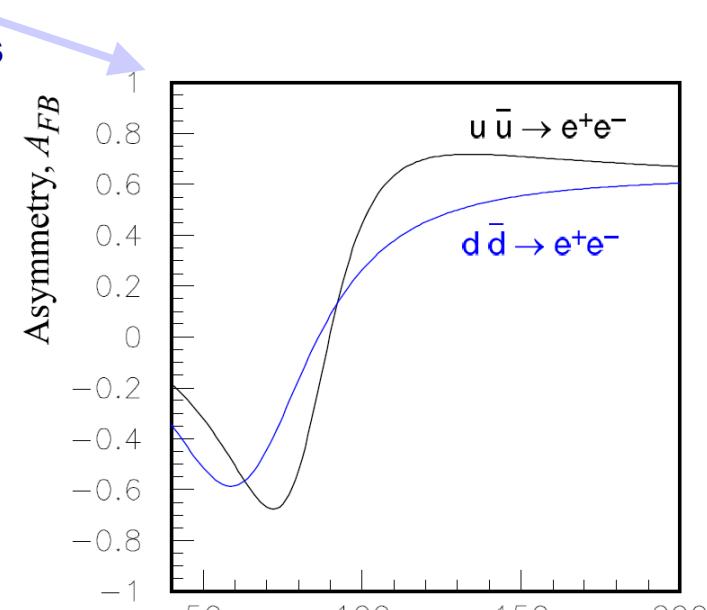
Bin data in P_T (2 bins) to increase sensitivity

Higher P_T prediction indicates that data has more pdf discrimination

Provides new PDF constraints → results available for PDF's 2005 fits

- Forward-backward asymmetry depends on v and a-v couplings of the quarks and leptons to the Z
(mix of v and a-v couplings changes with mass)
 A_{FB} vs mass has different sensitivity to u and d quarks
 - Sensitive to $\sin^2\theta_W$, but need high luminosity
(see J. Rha, and U. Baur, hep-ex/0011009)
- Can measure A_{FB} at CM energies above LEP II energy
 - Confirm γ^*/Z interference (dominates at high CM energy)
 - Study possible new phenomena that affects A_{FB} :
Z', extra dimensions,...
 - $A_{FB} \sim 0.6$ in SM
- Electron angle measured in Collins-Soper frame to minimize the effects of the transverse momentum of incoming quarks.
- Unfolding method for acceptance and bin migration

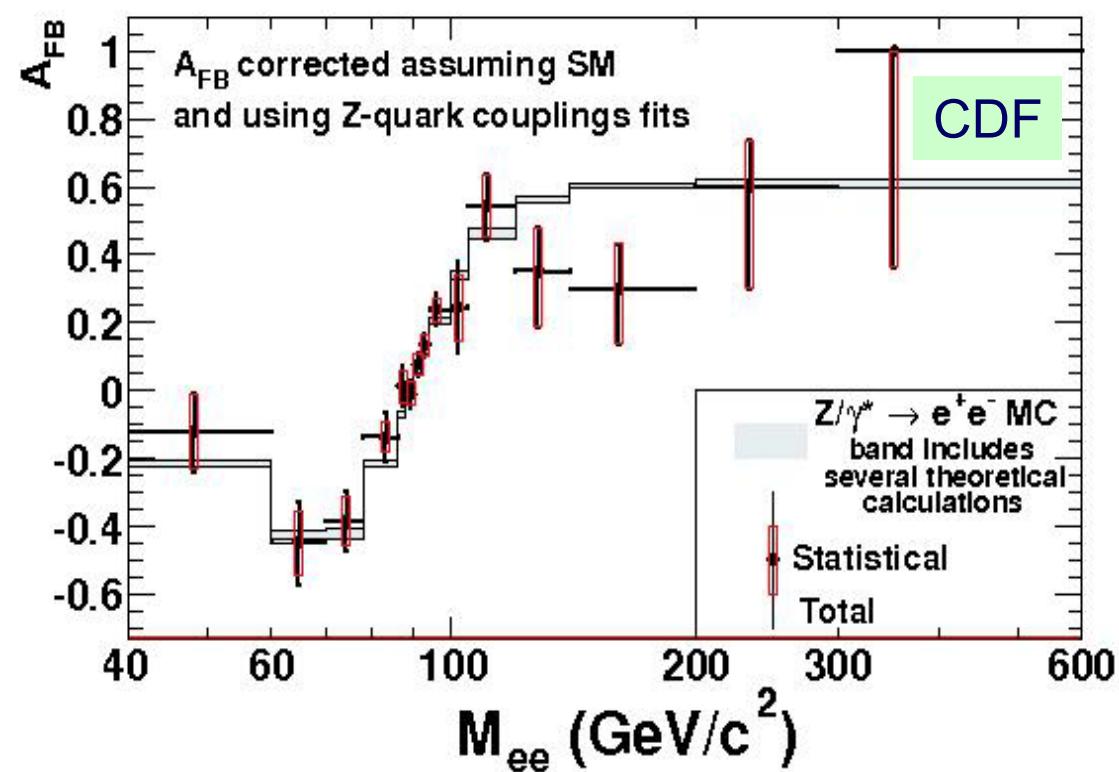
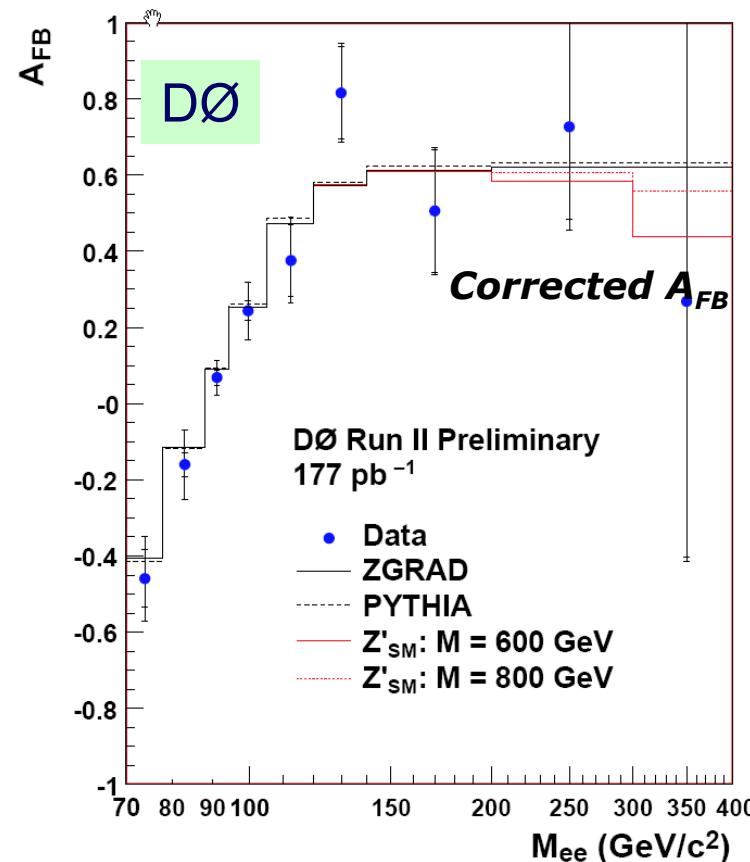
$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$



Select $Z/\gamma^* \rightarrow ee$ events

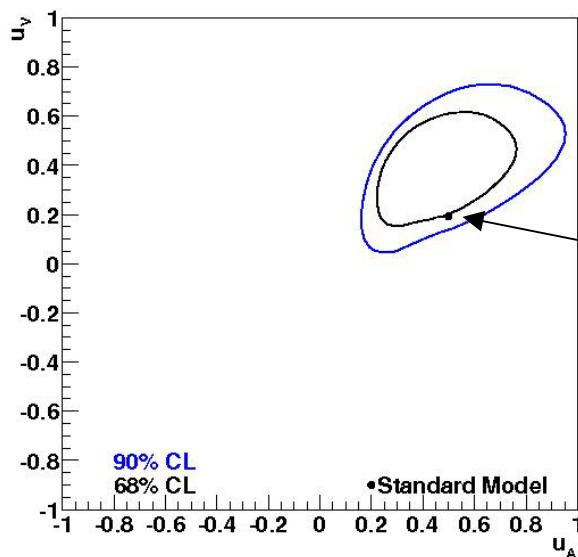
- electron $E_T > 25$ GeV (20 GeV @ CDF), $|\eta| < 1.1$
- main background dijet ~1-2% (5% forward)
- charge sign measurement !

Int. lum. DØ = 177 pb⁻¹ CDF = 72 pb⁻¹ (PRD 71, 052002)

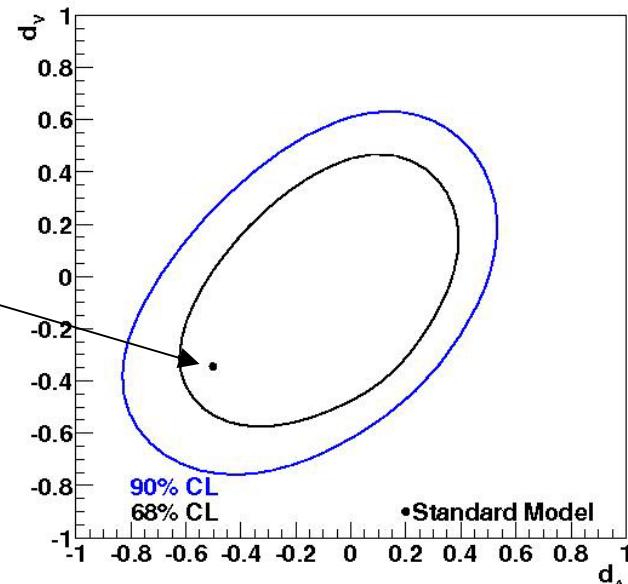


In agreement with SM: $A_{FB} \sim 0.6$ at high M_{ee}
needs statistics !

Z-quark couplings



SM



Contours at 68% and 90% u and d quark couplings to Z in the vector-, axial-vector basis

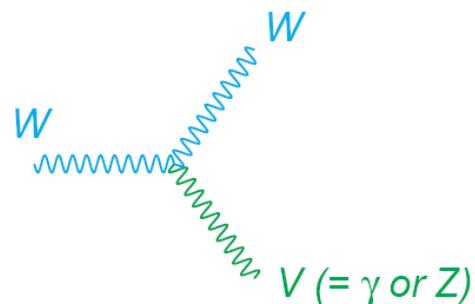
Z-electrons couplings

K. Hagiwara et al
Phys. Rev. D66, 010001 (2002)

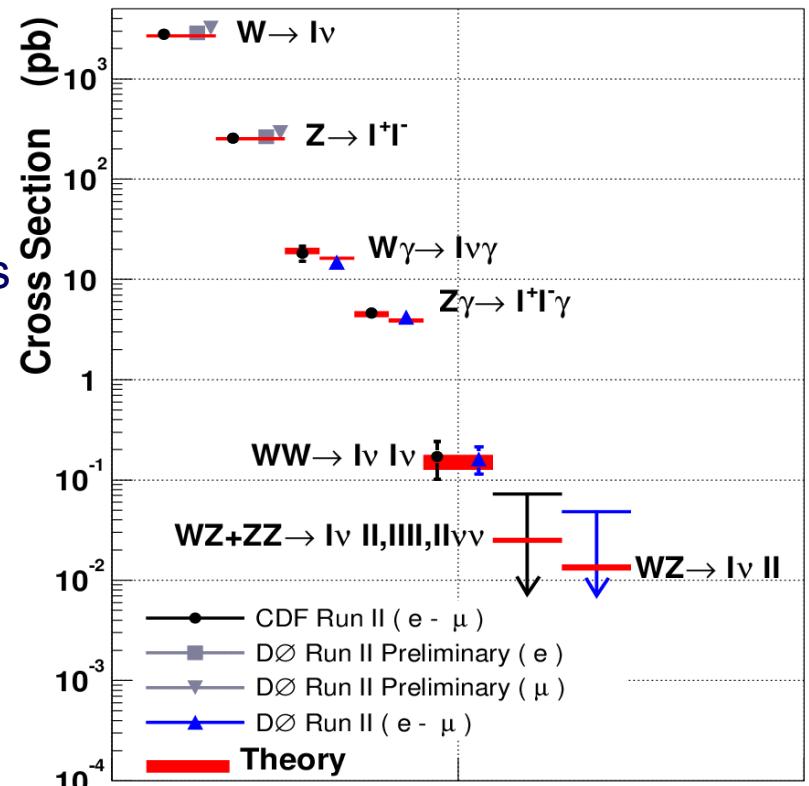
	coupling	Total err.	SLD+LEP hep-ex/0412015	SM pred.
e_V	-0.058	0.017	-0.03816 ± 0.00047	-0.0397 ± 0.0003
e_A	-0.528	0.136	-0.50111 ± 0.00035	-0.5064 ± 0.0001

$$\sin^2\theta_W^{\text{eff}}$$

CDF: $\sin^2\theta_W^{\text{eff}} = 0.2238 \pm 0.0040(\text{stat}) \pm 0.003(\text{sys})$



- Probing Non-Abelian structure of SM:
test of Triple Gauge Couplings
- Stringent limits from LEP but Tevatron
is complementary:
 - explores higher center of mass and p_T values
 - probes different coupling combinations
than LEP
 - competitive with few fb^{-1}
- New physics probe (Anomalous Couplings)
- Background of numerous analyses
($H \rightarrow WW$, SUSY, $t\bar{t}$ tbar)
- As 10^{-2} to 10^{-4} of single production σ
too low statistics at Run I \rightarrow low significance
on diboson signal



Characterized by an effective Lagrangian:
parametrization of new physics in terms of coupling parameters

$$\begin{aligned} \mathcal{L}_{WWV}/g_{WWV} = & g_V^1 (W_{\mu\nu}^\dagger W^{\mu\nu} - W_\mu^\dagger V_\nu W^{\mu\nu}) \\ & + \kappa_V W_\mu^\dagger W_\nu V^{\mu\nu} + \frac{\lambda_V}{M_W^2} W_{\lambda\mu}^\dagger W_\nu^\mu V^{\nu\lambda} \end{aligned}$$

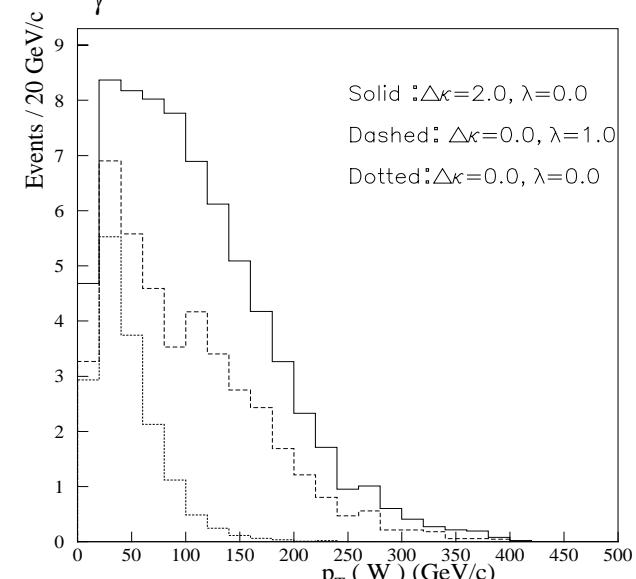
Phys. Rev. D48(5) 2182 (HISZ)

5 C and P conserving parameters ($g_\gamma^{-1} = 1$ em gauge invariance)
SM parameters $g_Z^{-1} = g_\gamma^{-1} = \kappa_Z = \kappa_\gamma = 1$; $\lambda_Z = 0$ $\lambda_\gamma = 0$

Cross section with non-SM couplings
grows with subprocess CM energy
→ form factor

$$a(\hat{s}) = \frac{a_0}{\left(1 + \hat{s}/\Lambda_{FF}^2\right)^2} \quad \left. \begin{array}{l} \hat{s} = \text{subprocess CM energy} \\ \Lambda_{FF} = \text{form factor scale} \end{array} \right\}$$

$\Lambda_{FF} \sim 1$ to 2 TeV



high p_T bosons(W/Z/γ)



Anomalous Couplings – LEP and Tevatron



- DØ and CDF put limits on anomalous $WW\gamma$ and WWZ Couplings in Run I.
- DØ Combined $W\gamma$, WW, WZ (1999)
- LEP ALO Combined (1D 68% CL)
(LEPEWWG/TGC/2005-01 June 2005)

– $0.29 < \Delta \kappa_\gamma < 0.53$
– $-0.18 < \lambda_\gamma < 0.19$
95% C.L. **tightest limits**
 $\Lambda = 2$ TeV **at Tevatron**

$$\begin{aligned}\kappa_\gamma &= 0.973 + 0.044 - 0.045 \\ \lambda_\gamma &= -0.028 + 0.020 - 0.021 \\ g_1^Z &= 0.984 + 0.022 - 0.019\end{aligned}$$

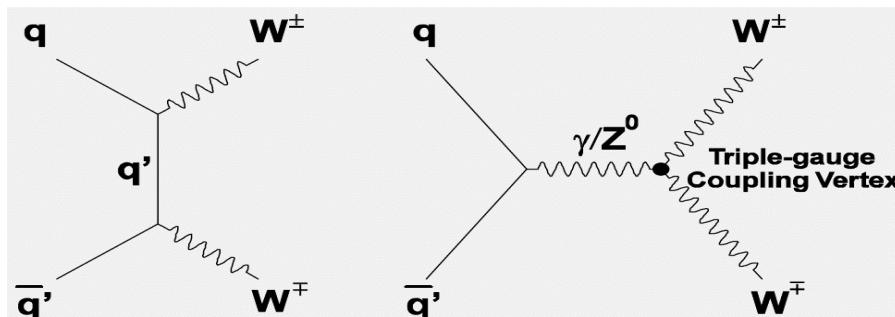
C and P, $U(1)_{em}$ and global $SU(2) \otimes U(1)$

$$\lambda_\gamma = \lambda_Z \text{ and } \kappa_Z = g_1^Z - \tan^2 \theta_w (\kappa_\gamma - 1)$$

LEP does not use a form-factor dependence in the couplings.

2 parameters :
w/ constraint (D0) $g_1^Z = \frac{(\kappa_\gamma - 1)}{2 \cos^2 \theta_w} + 1$
“HISZ” $SU(2) \otimes U(1)$ coupling relations

Phys.Rev. D48(5) 2182 (HISZ)



t channel ~90%

s-channel ~10%

Dileptons

$e\mu\nu\nu$ and $\mu\mu\nu\nu$
Br = 2.5 and 1.2%

*Pure and
efficient
Low branching
Frac.*

Lepton+jets

$e\nu + \text{jets}$, $\mu\nu + \text{jets}$
Br = 15%

*Efficient
Not very
pure*

All-jets

All-jets
Br = 47%

*Very
Efficient
Never Mind*

- Sensitive to WWZ / $WW\gamma$
- Dileptons analysis: ee , $\mu\mu$, $e\mu$ (CDF/D \emptyset)
 - clean, but low branching fraction
 - 2 isolated opposite charged leptons
 - large E_T Miss (2ν)

- Main Backgrounds to dileptons channel:

- $W+j/\gamma$ ~ 500 pb
- Drell-Yan ~ 250 pb
- top pairs ~ 0.1 pb
- WZ , ZZ

CDF (184 pb⁻¹)

DØ (224-252 pb⁻¹)

Process	ee	$\mu\mu$	e μ	ee	$\mu\mu$	e μ
WW signal	2.6 ± 0.3	2.5 ± 0.3	5.1 ± 0.6	3.42 ± 0.05	2.10 ± 0.05	11.10 ± 0.10
Total BKG	$1.9^{+1.3}_{-0.3}$	$1.3^{+1.6}_{-0.4}$	1.9 ± 0.4	2.30 ± 0.21	1.95 ± 0.41	3.81 ± 0.17
Observed	6	6	5	6	4	15

CDF cross-check
1 lepton
+ 1 isolated track

$$\sigma(WW) = 14.6^{+5.8}_{-5.1} (stat.)^{+1.8}_{-3.0} (sys.) \pm 0.9 (lum.) \text{ pb}$$

PRL 94, 211801 (2005)

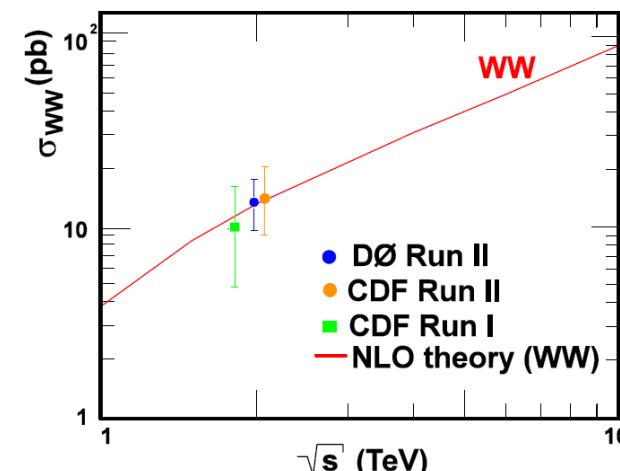
$$\sigma(WW) = 13.8^{+4.3}_{-3.8} (stat.)^{+1.2}_{-0.9} (sys.) \pm 0.9 (lum.) \text{ pb}$$

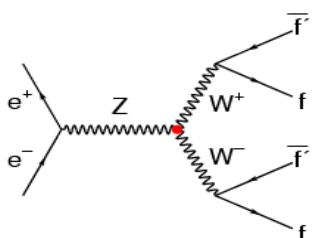
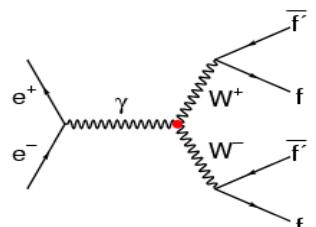
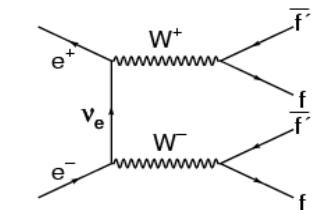
PRL 94, 151801 (2005)

$$\sigma_{WW}^{\text{LTRK}} = 24.2 \pm 6.9 (\text{stat})^{+5.2}_{-5.7} (\text{syst}) \pm 1.5 (\text{lum}) \text{ pb}$$

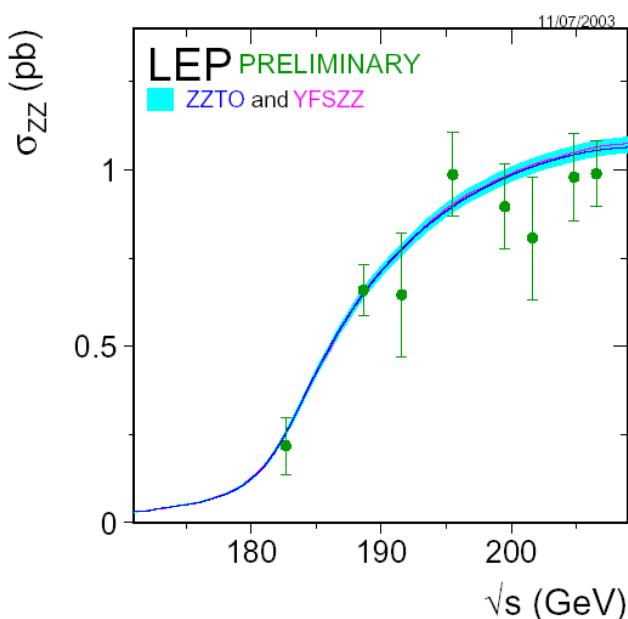
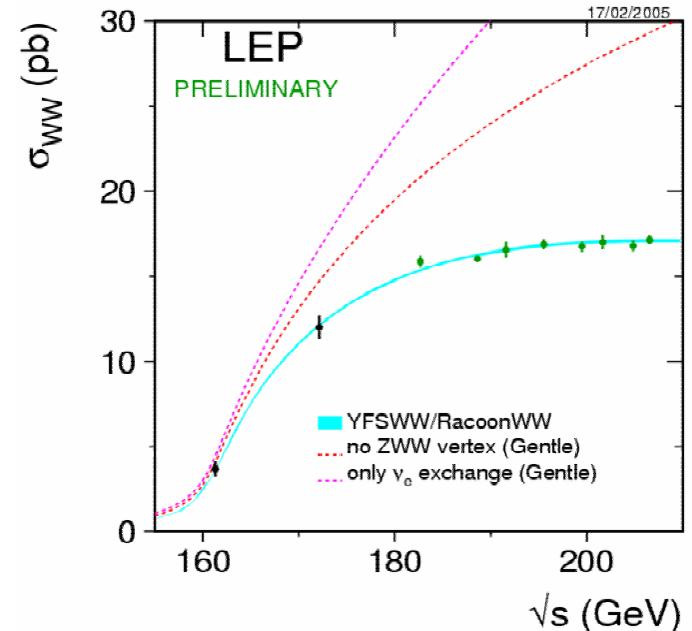
- Run II WW signal clearly established
- Good agreement with NLO:

$\sigma(pp \rightarrow WW \rightarrow llvv)^{\text{THEORY}}_{\text{NLO}} = 16.0 \pm 0.4 \text{ pb}$
 Baur & Berger , PRD 41 ,1476 (1999)



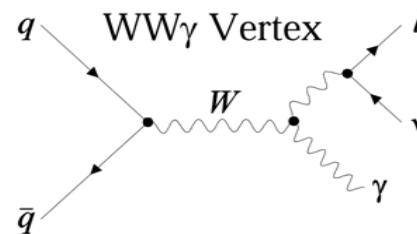
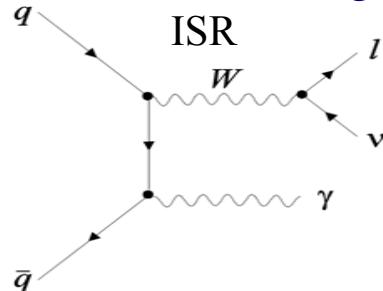


Clear proof of $SU(2) \times U(1)$
gauge couplings !

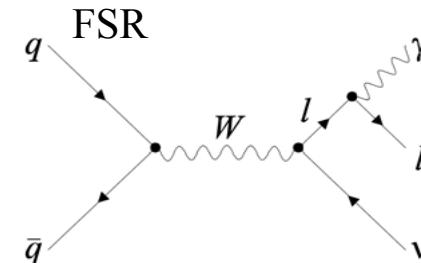


agreement with SM : theory~2%

Three diagrams contribute at LO



Probe trilinear WW γ couplings

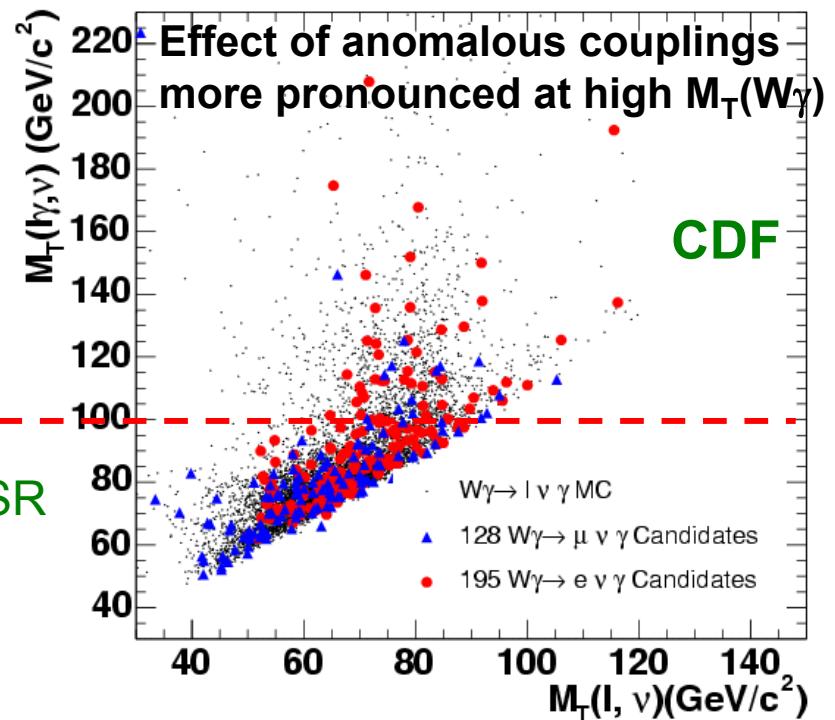


- W selection:
 - Isolated high P_T (e/μ) $> \sim 25$ GeV
 - large E_T $> \sim 25$ GeV
- Photon ID critical:
 - central $|\eta| < 1.1$
 - $\Delta R(l, \gamma) > 0.7$ (suppress FSR)

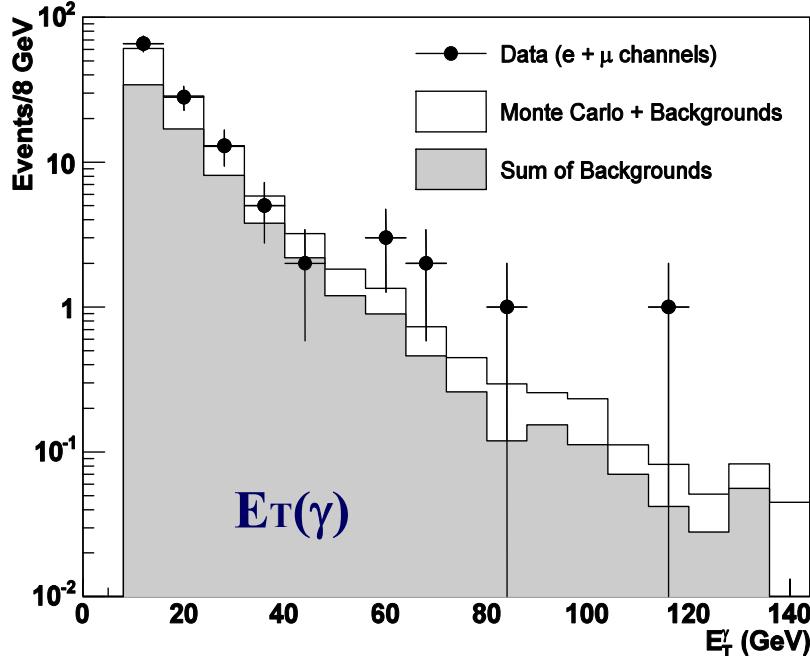
	$\sigma(pp \rightarrow W\gamma)$	SM, pb	E_T^{γ}
CDF	$18.1 \pm 1.6 \pm 2.4 \pm 1.2$	19.3 ± 1.4	7
DØ	$14.8 \pm 1.6 \pm 1.0 \pm 1.0$	16.0 ± 0.4	8

Both experiments quote cross section integrated over the acceptance

ISR
+
WW γ



DØ Combined channels



1D limits @ 95% C.L. $\Lambda_{FF} = 2 \text{ TeV}$

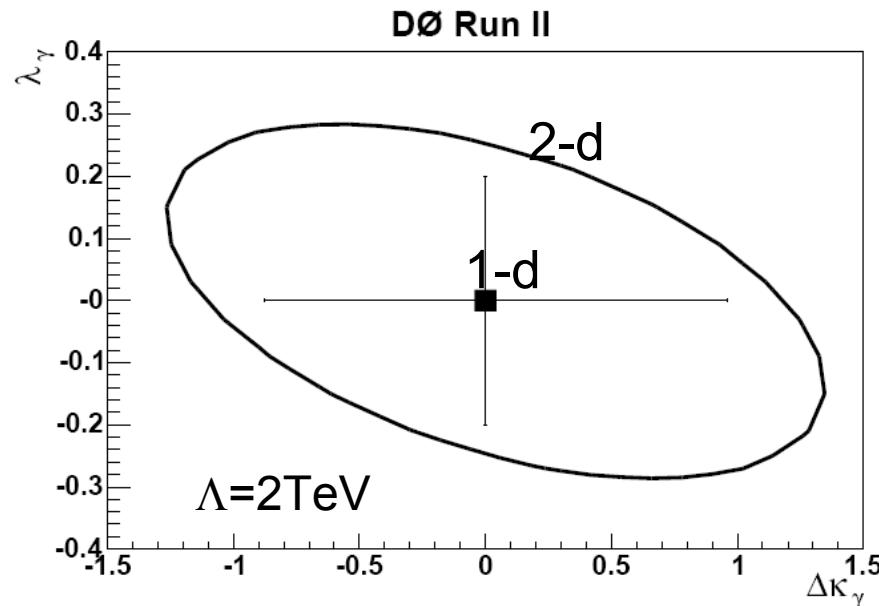
DØ	Tevatron Run I	Tevatron Run II
$\Delta\kappa_\gamma$	-0.93 , 0.94	-0.88, 0.96
λ_γ	-0.31, 0.29	-0.20, 0.20

better than Run I

PRD 71, 091108 (2005)

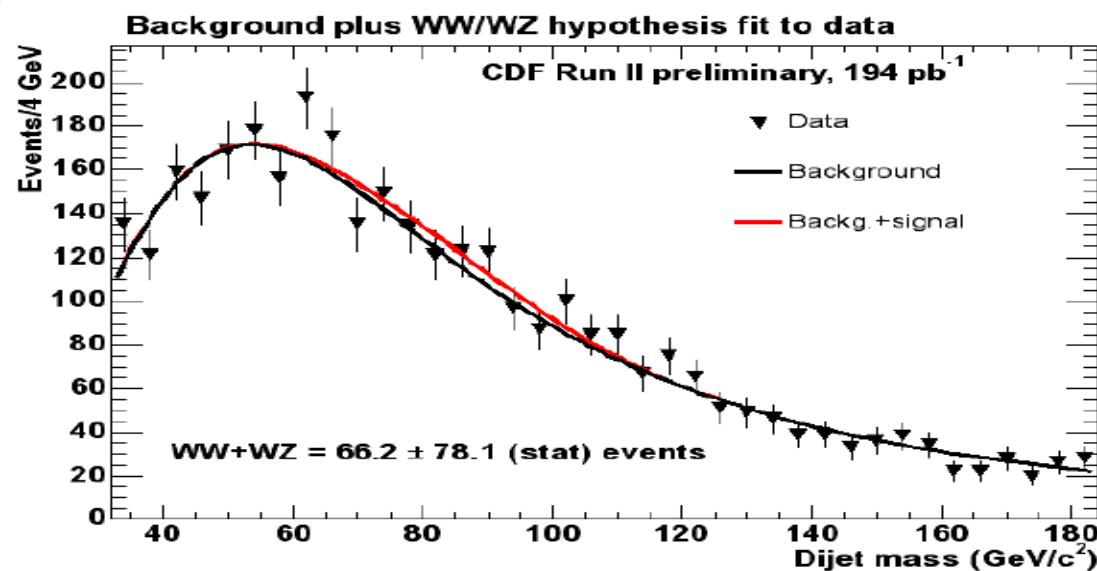
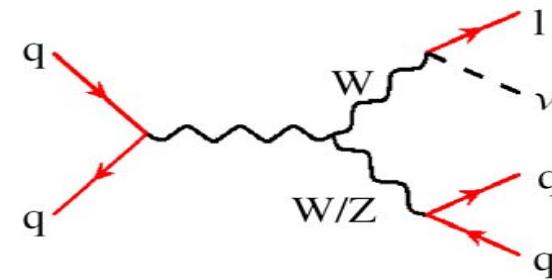
- photon $E_T(\gamma)$ distribution (sensitive to new physics) agrees with SM
- Form a binned-likelihood based on $E_T(\gamma)$ in a λ_γ vs. $\Delta\kappa_\gamma$ grid including bkgd on events w/ $M_{T(W,\gamma)} > 90 \text{ GeV}/c^2$ to enhance WW γ contribution

Hagiwara et al Phys Rev D41, 2113 (1990)



- CDF has recently performed a search for WW/WZ production, where $W \rightarrow l\nu$ ($l=e,\mu$) and W/Z decays hadronically into two jets
 - Higher branching ratio but also much higher backgrounds
 - Dominant background is W+2jets production, which is constrained by fitting to dijet mass sidebands
- Fitting signal+background to signal region returns

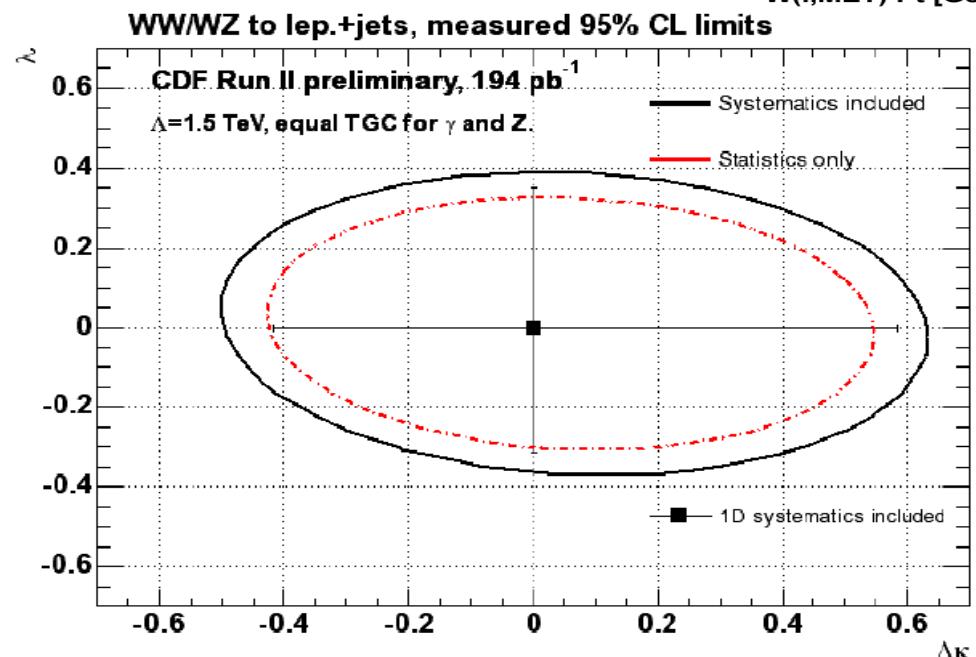
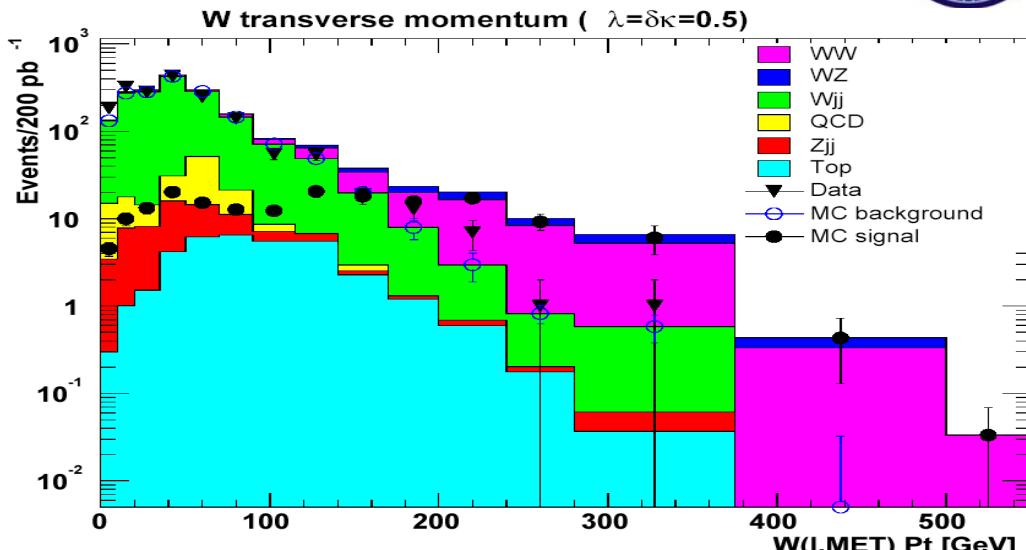
$N_{\text{sig}} = 66 \pm 78 \pm 34$ ($N_{\text{SM}} = 91$)
 $N_{\text{sig}} < 40$ pb (95% CL)
 194 pb⁻¹



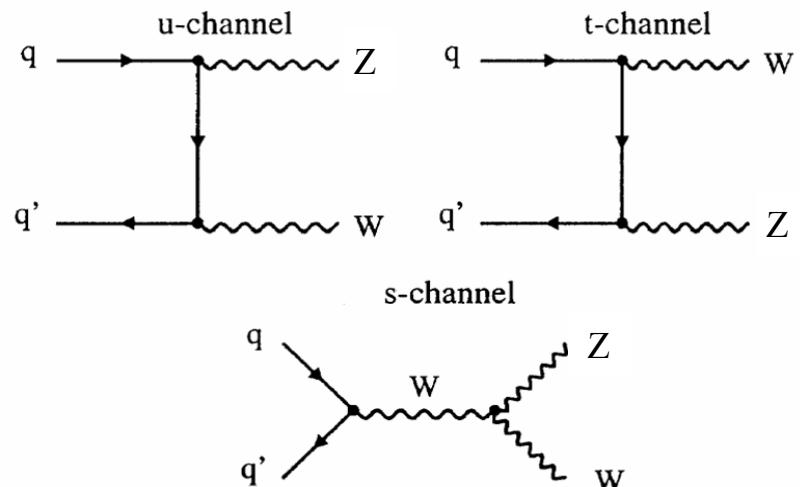
- anomalous interaction terms are parametrized by $\Delta\kappa$ and λ
- The P_T of the W formed from the lepton and the missing E_T (ν) is found to be the most sensitive probe – anomalous VV pairs are produced with high P_T
- 95% CL limits obtained are:

$$\begin{aligned} -0.42 < \Delta\kappa < 0.58 \\ -0.32 < \lambda < 0.35 \end{aligned}$$

$\Lambda=1.5$ TeV equal TGC for γ and Z



- Sensitive to WWZ vertex
 - cf. WW production, which depends on WWZ **and** WW γ
 - Allows study of WWZ coupling parameters with ***no assumptions*** about WW γ couplings
 - unavailable at LEP
- SM cross section is 3.7 pb (J.M Campbell and R.K. Ellis)
- WZ $\rightarrow l\nu l^+l^-$ mode is clean and unambiguous
 - but has low branching fraction 1.5%
- WZ $\rightarrow l\nu jj$ mode has larger branching fraction (15%)
 - Main background: WZ from W+jets, WW



Z selection:

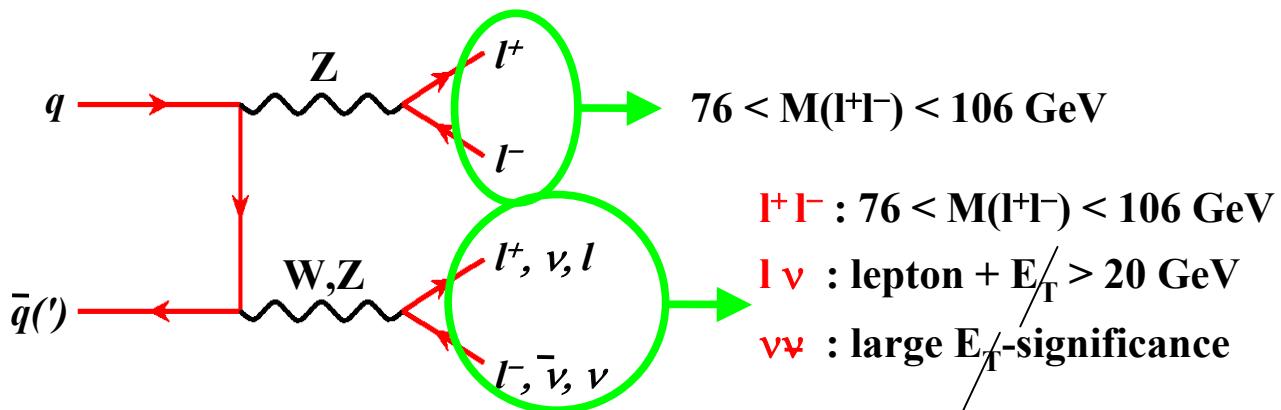
- 2 high P_T leptons (ee or $\mu\mu$)
- $M_{inv}(ll)$ consistent with M_Z

W selection:

- isolated lepton + E_T Miss

Main background:

- $Z/\gamma^* + \text{jet}$



194 pb⁻¹

$\sigma(p \bar{p} \rightarrow WW/WZ) < 15.2 \text{ pb } 95\% \text{ C.L.}$

Phys. Rev. D 71, 091105 (2005)

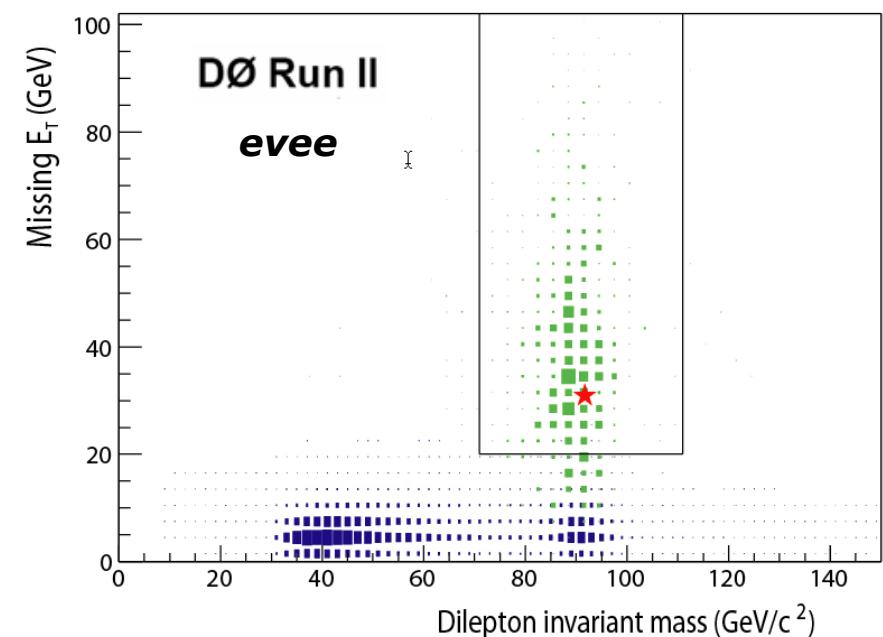
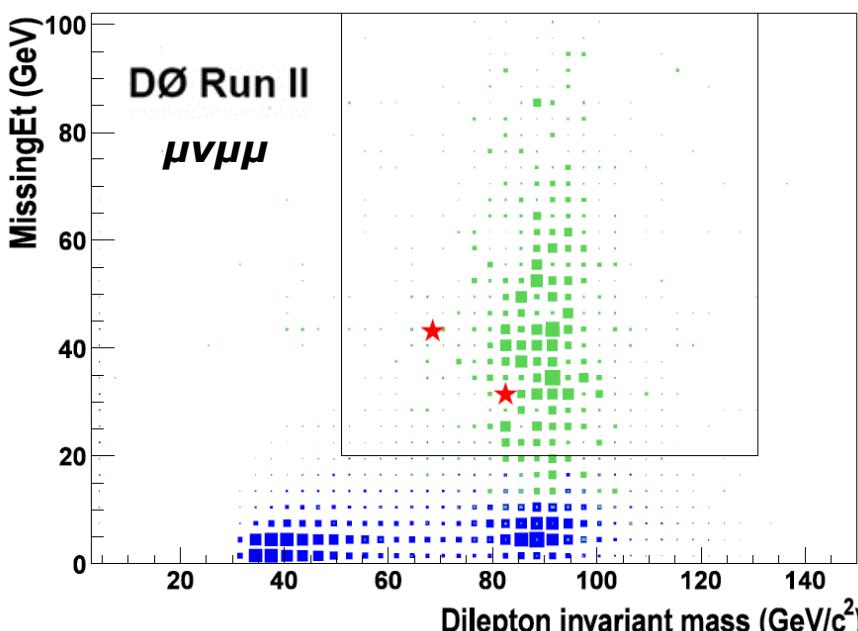
$\sigma(p \bar{p} \rightarrow WW/WZ)_{\text{NLO}} < 5.0 \pm 0.4 \text{ pb}$
J.M Campbell and R.K. Ellis Phys. Rev. D 60, 1448 (1992)

$\int L dt = 320 \text{ (evee), } 290 \text{ (}\mu\nu\text{ee)}$

$280 \text{ (}e\nu\mu\mu\text{), } 290 \text{ (}\mu\nu\mu\mu\text{) pb}^{-1}$

- Event selection
 - 3 charged leptons $p_T > 15 \text{ GeV}$, missing $E_T > 20 \text{ GeV}$, M_Z window
- Candidates:
 - 2 $\mu\nu\mu\mu$ events, 1 $e\nu ee$ event

- Total estimated background
 $= 0.71 \pm 0.08$
 - $Z + \text{jet}$
 - Other backgrounds are from $Z\gamma, ZZ$, and $t\bar{t}$



DØ

- Probability of background of 0.71 events to fluctuate to three or more candidates is 3.5%

- Assume excess events due to WWZ signal: **Cross section**

$$\sigma(p\bar{p} \rightarrow WZ) = 4.5^{+3.8}_{-2.6} \text{ pb}$$

$< 13.3 \text{ pb at the 95\% C.L.}$

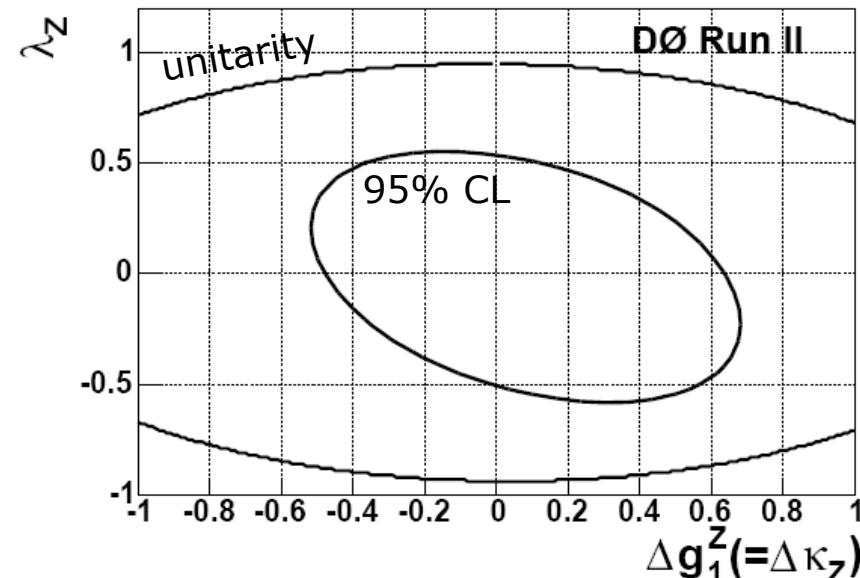
- In agreement with SM (Campbell+Ellis 1999)

$$\sigma_{SM}^{NLO}(p\bar{p} \rightarrow WZ) = 3.7 \pm 0.1 \text{ pb}$$

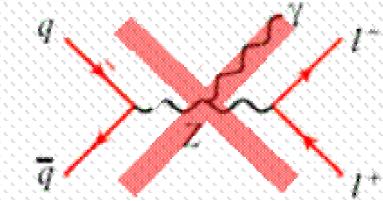
95% CL limits on WWZ coupling parameters for $\Lambda_{FF} = 1.5 \text{ TeV}$:

Condition	Limits
$\Delta g_1^Z = \Delta \kappa_Z = 0$	$-0.53 < \lambda_Z < 0.56$
$\lambda_Z = \Delta \kappa_Z = 0$	$-0.57 < \Delta g_1^Z < 0.76$
$\lambda_Z = \Delta g_1^Z = 0$	$-2.0 < \Delta \kappa_Z < 2.4$
$\lambda_Z = 0, \Delta g_1^Z = \Delta \kappa_Z$	$-0.49 < \Delta g_1^Z = \Delta \kappa_Z < 0.66$

- 95%CL 2-d limits for for $\Lambda_{FF} = 1.5 \text{ TeV}$, with $\Delta g_1^Z = \Delta \kappa_Z$:



- Best limits on WWZ coupling
- Model-independent (no WWγ coupling assumptions)
- Submitted to PRL , hep-ex(0504019)



= 0 ?? → Anomalous Couplings

Z γ selection:

- 2 high- P_T isolated leptons
- $40 < M_{\text{inv}}(l, l) < 110 \text{ GeV}$
- 1 photon $|\eta| < 1.1$ with $\Delta R(l\gamma) > 0.7$
- $E_T > 7 \text{ GeV (CDF)} 8 \text{ GeV (D}\emptyset)$

main background is from $Z + \text{jet}$
where jet mimics a photon

$\sigma(p\bar{p} \rightarrow Z(l\bar{l})\gamma)$ in pb :

CDF $\sim 200 \text{ pb}^{-1} = 4.6 \pm 0.5 \text{ Stat+Syst} \pm 0.3 \text{ Lum}$

CDF: PRL 94, 041803 (2005)

SM * = 4.5 ± 0.3

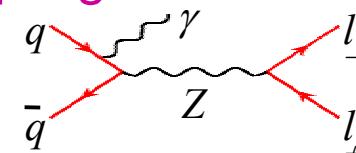
D \emptyset $\sim 300 \text{ pb}^{-1} = 4.2 \pm 0.4 \text{ Stat+Syst} \pm 0.3 \text{ Lum}$

SM * = 3.9 ± 0.2

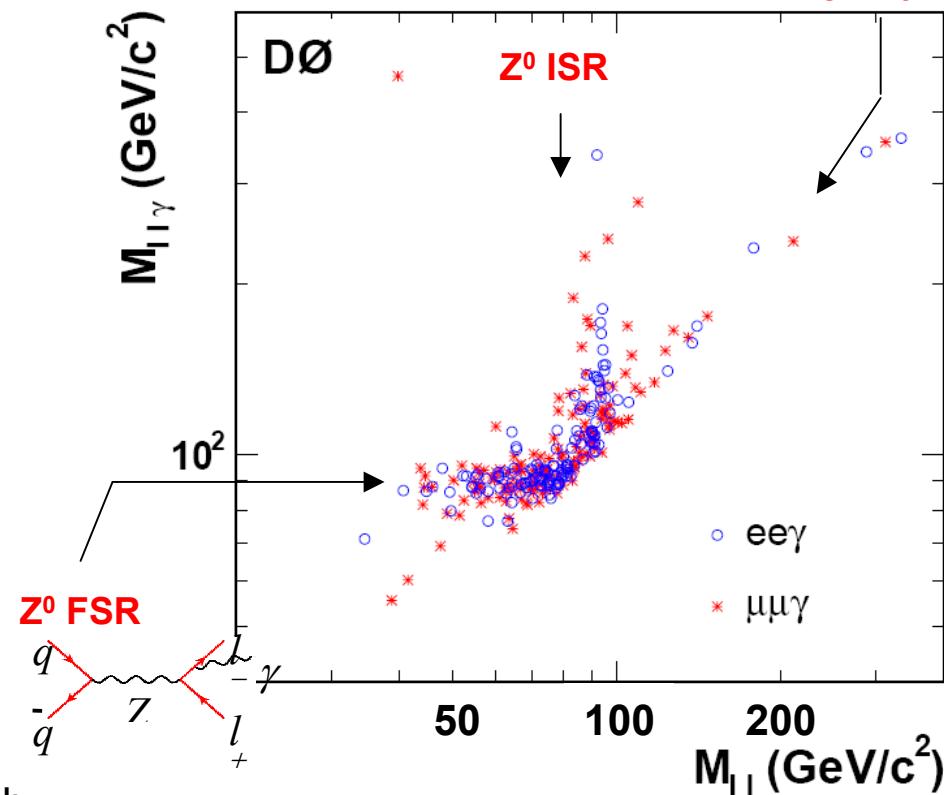
• From Baur, Han and Ohnemus

• Both experiments quote cross section integral with
the acceptance

9/9/2005

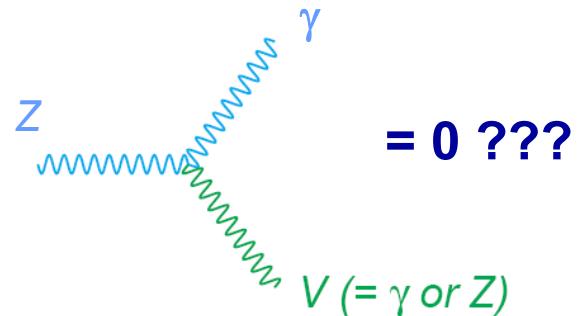


Drell-Yan



- **Effective Lagrangian**

$$L_{Z\gamma V} = -ie \left[\left(h_1^V F^{\mu\nu} + h_3^V \tilde{F}^{\mu\nu} \right) Z_\mu \frac{(\square + m_V^2)}{m_Z^2} V_\nu \right] \\ - ie \left[\left(h_2^V F^{\mu\nu} + h_4^V \tilde{F}^{\mu\nu} \right) Z^\alpha \frac{(\square + m_V^2)}{m_Z^4} \partial_\alpha \partial_\mu V_\nu \right]$$



- h_1^V and h_2^V violate CP;
- h_3^V and h_4^V conserve CP
- All coupling parameters are zero in the SM at tree-level
- Form factor to ensure unitarity

$$a(\hat{s}) = \frac{a_0}{\left(1 + \hat{s}/\Lambda_{FF}^2\right)^n} \quad \left. \right\} \begin{array}{l} \hat{s} = \text{subprocess CM energy} \\ \Lambda_{FF} = \text{form factor scale} \end{array}$$

$$n = 3 \text{ for } h_{1,3}^V \text{ and } n = 4 \text{ for } h_{2,4}^V$$

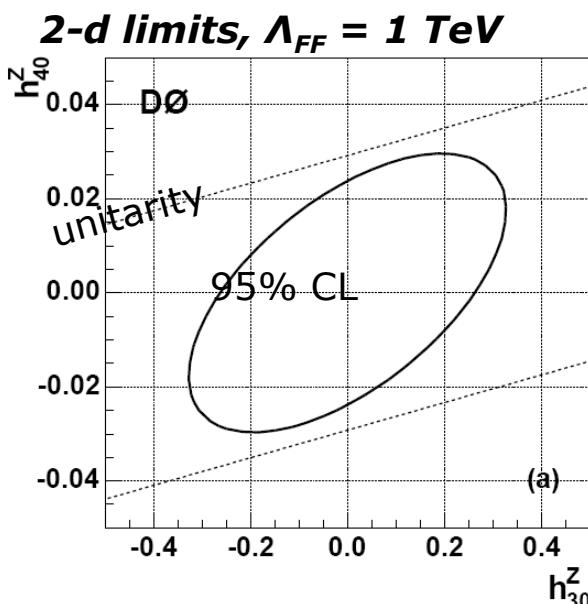
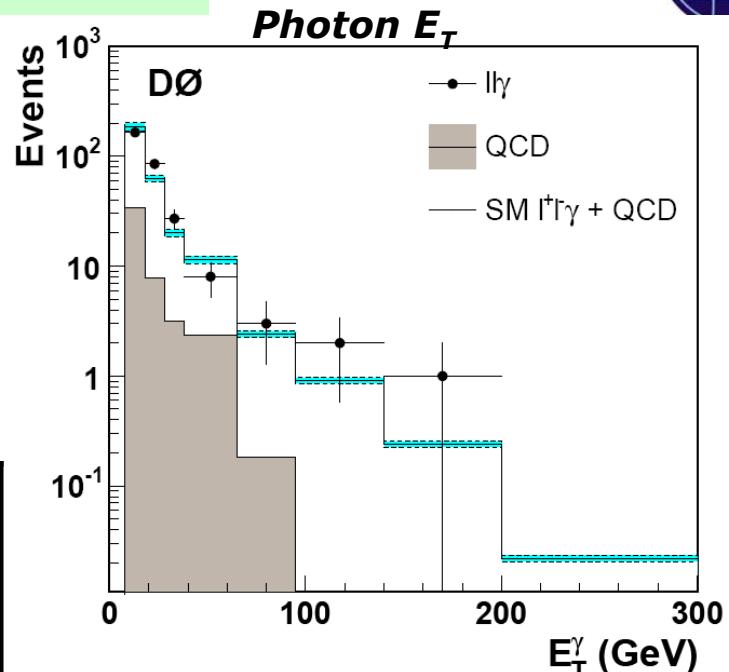
- Limits on anomalous couplings set using maximum likelihood fit to photon E_T spectrum
- 95% CL 1-d limits for $\Lambda_{FF} = 1 \text{ TeV}$:

LEP	Tevatron (D \emptyset)
$-0.049 < h_{30}^\gamma < 0.008$	$-0.23 < h_{30}^\gamma < 0.23$
$-0.002 < h_{40}^\gamma < 0.034$	$-0.019 < h_{40}^\gamma < 0.019$
$-0.20 < h_{30}^Z < 0.07$	$-0.23 < h_{30}^Z < 0.23$
$-0.05 < h_{40}^Z < 0.12$	$-0.02 < h_{40}^Z < 0.02$



better than LEP !

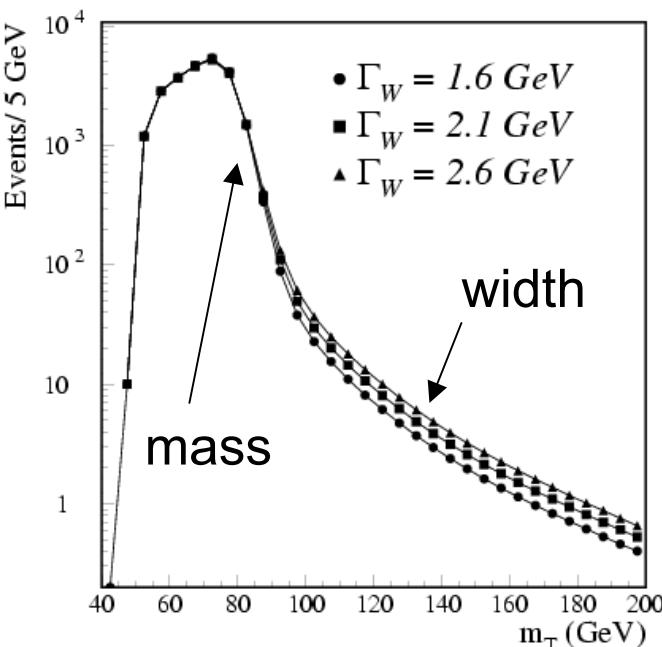
submitted to PRL hep-ex/0502036



Published: Phys. Rev. D70: 092008, 2004

Correlated uncertainties on W mass

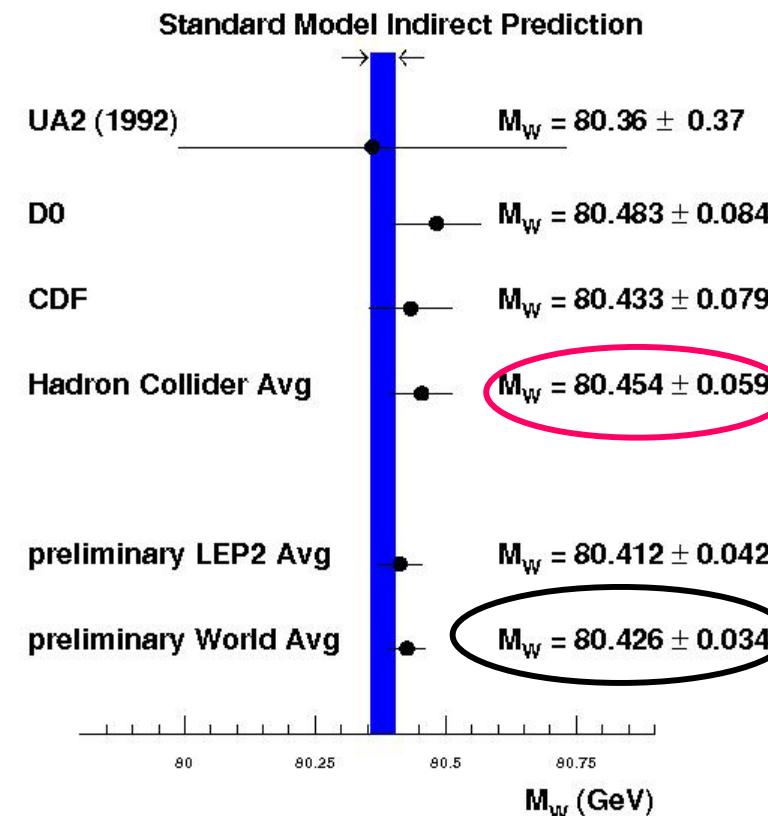
	CDF	DØ
PDF	15	8
Radiative corr	11	12
W width	10	10
Total	19 MeV	



require the best knowledge of the detectors !

Uncorrelated uncertainties statistics

lepton scale and resolution
 $p_T(W)$ and recoil
background



Method: fit the transverse mass distribution in the region $100 < M_T(W) < 200$ GeV

Selection: 75K $W \rightarrow e\nu$ $|\eta| < 1.1$

625 candidates with
 $100 < M_T(W) < 200$ GeV

Preliminary Result:

$$\Gamma_W = 2.011 \pm 0.093 \text{ (stat)} \pm 0.099 \text{ (sys)}$$

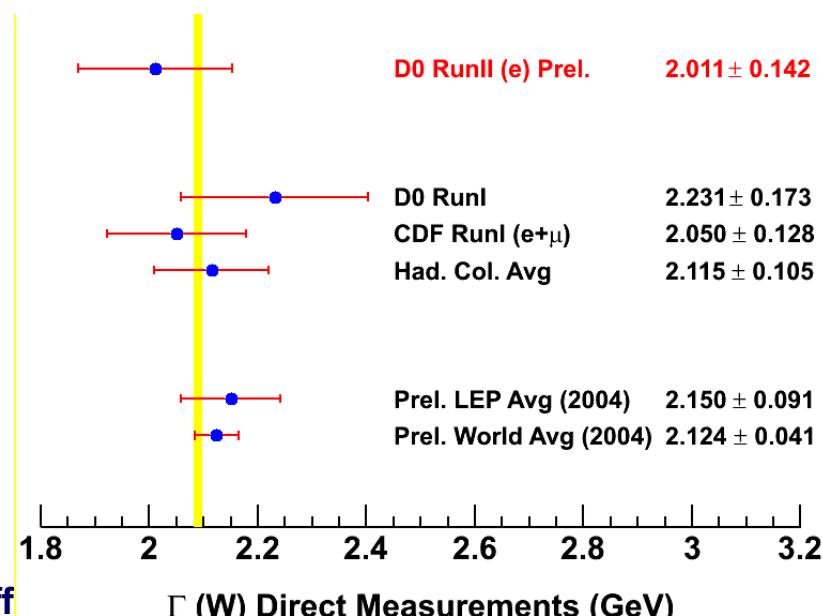
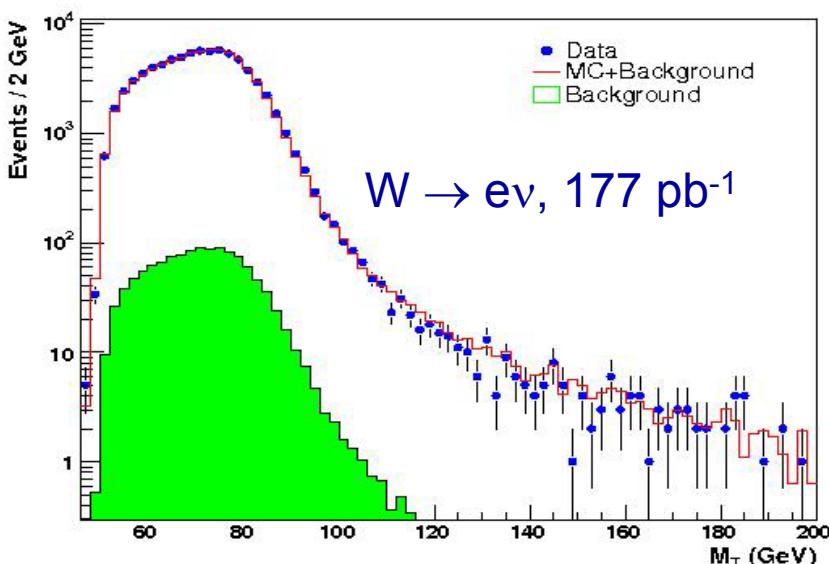
Main systematic uncertainties:

Hadronic response and resolution ~ 64 MeV

Underlying event ~ 47 MeV

EM resolution ~ 30 MeV

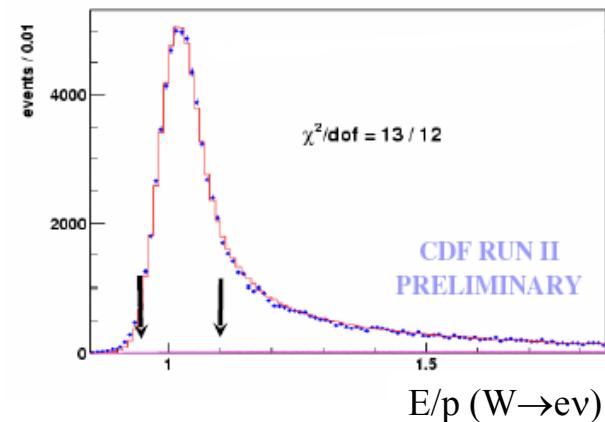
Result already competitive, a lot of room for improvement !



$W \rightarrow e/\mu\nu$, $\sim 200 \text{ pb}^{-1}$, first part of analysis complete, uncertainties determined

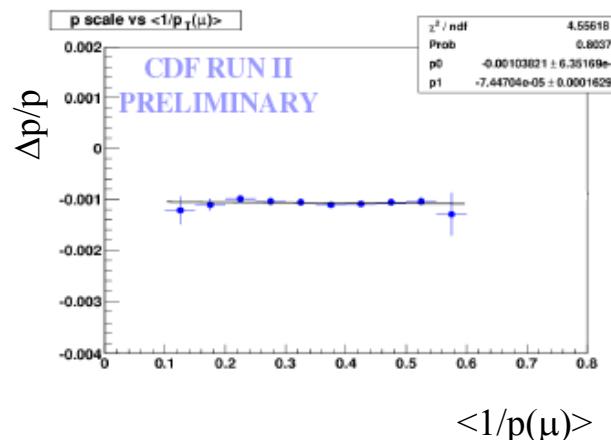
Electron channel

Energy scale using E/p



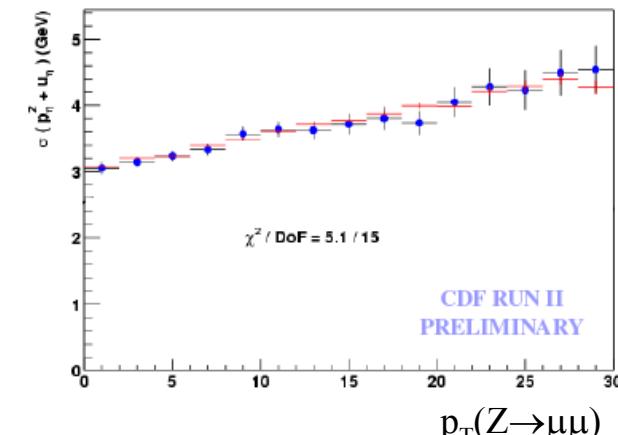
Muon channel

p scale using J/Ψ and Υ



Recoil model

Tune using $Z \rightarrow \mu\mu$

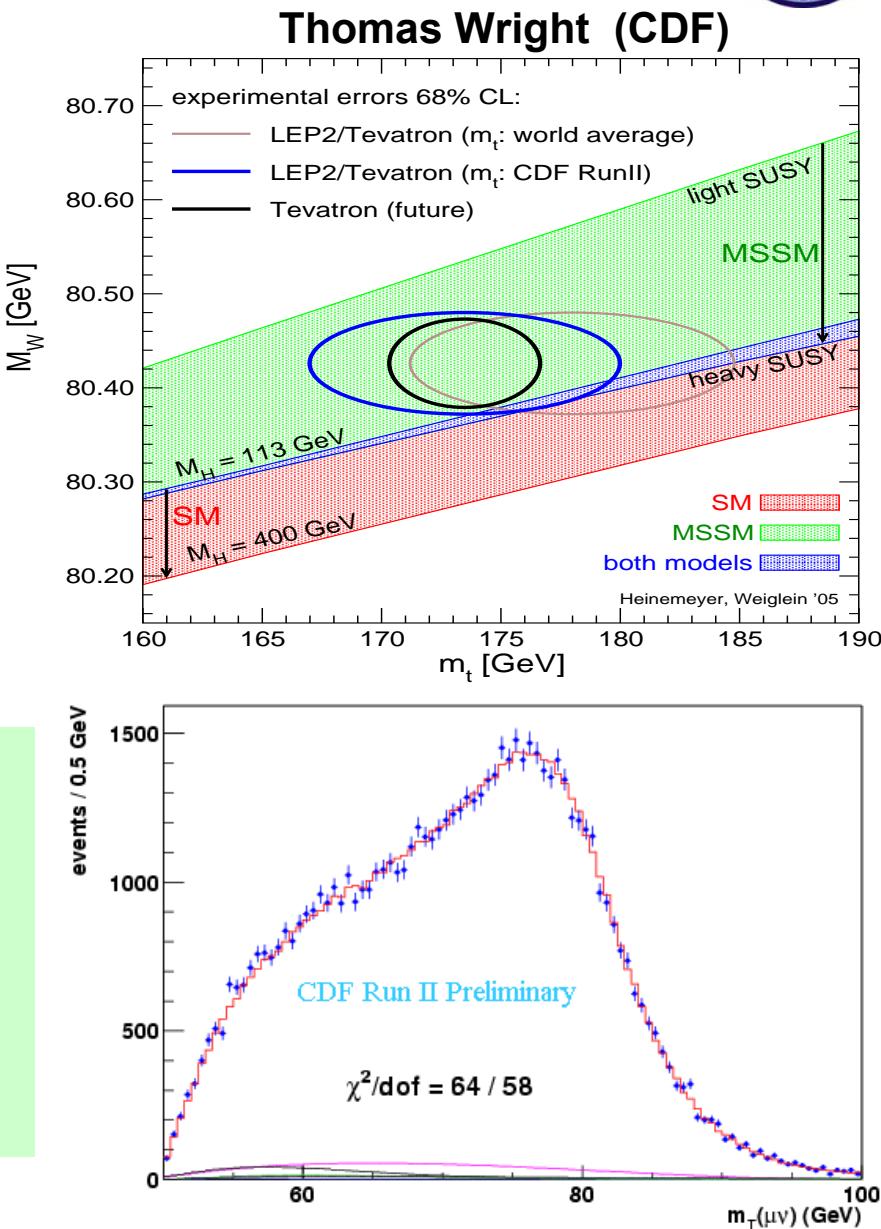


Systematic uncertainties in MeV

	e	μ
Lepton energy scale and resolution	70	30
Recoil scale and resolution	50	50
Statistics	45	50
Production and decay model	30	30
Background	20	20

Total: 76 MeV (RunI: 79 MeV)

- accuracy ! $\delta M_W = 34 \text{ MeV}$ (0.042%)
- fit $M_T(W)$ the most accurate
- Theoretical/phenomenological inputs
 - QED radiation (WGRAD)
 - QCD: W P_T spectrum (Resbos)
 - PDF's
 - uncertainties on W mass $\sim 30 \text{ MeV}$
- CDF: 200 pb^{-1} $W \rightarrow e/\mu$ “blind measurement”
uncertainties = 76 MeV (better than Run I)
- $>1 \text{ fb}^{-1}$ other sources than theory $\sim 30 \text{ MeV}$
→ theoretical uncertainties could become important !
- no final LEP combination on the W mass (?)



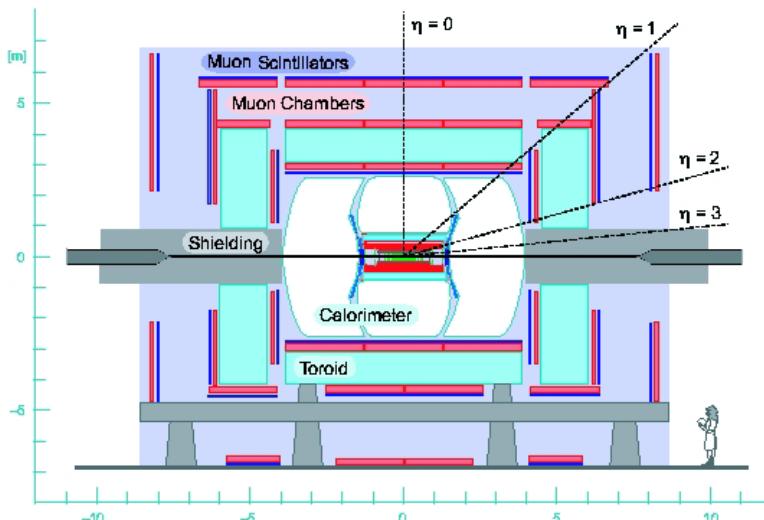
- Improved results compared to Run I
- More and more competitive with LEP
- $Z \rightarrow \tau \tau$: a milestone in $p\bar{p}$ collider physics
- W assymetry \rightarrow PDF's 2005 fits
- First Run II measurement of the W width
- New results on diboson production important step towards the Higgs search
- Looking forward to high precision EWK measurements:
 - W mass, width, branching ratio
 - Precision diboson measurements
 - W charge/FB Z/ γ asymmetries



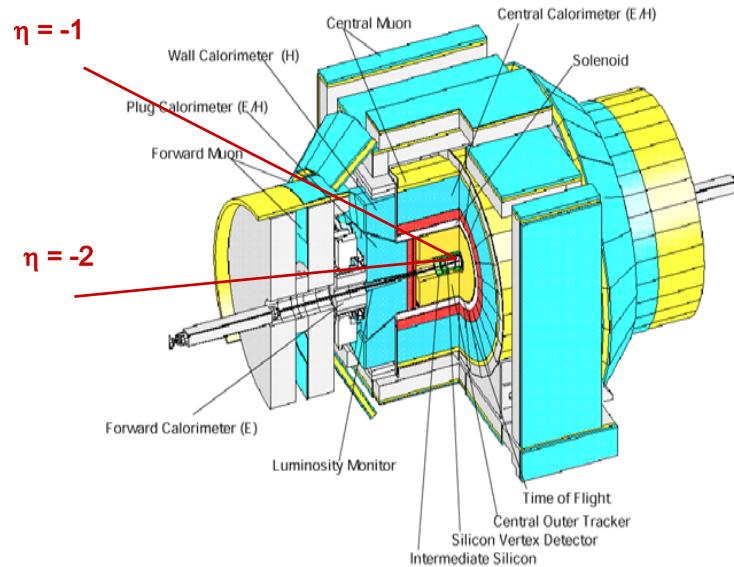
Tevatron experiments just starting to explore potential of Run II data !
results with 1 fb-1 very soon ..stay tuned !!



Backup Slides



DZero Run II upgrades
2T solenoid
inner tracking
Preshower
extended μ coverage
and shielding
Trigger, DAQ



CDF Run II upgrades
Inner tracking
Forward calorimeter
extended μ coverage
Trigger, DAQ

recorded $.850 \text{ fb}^{-1}$
data taking efficiency $\sim 85\%$

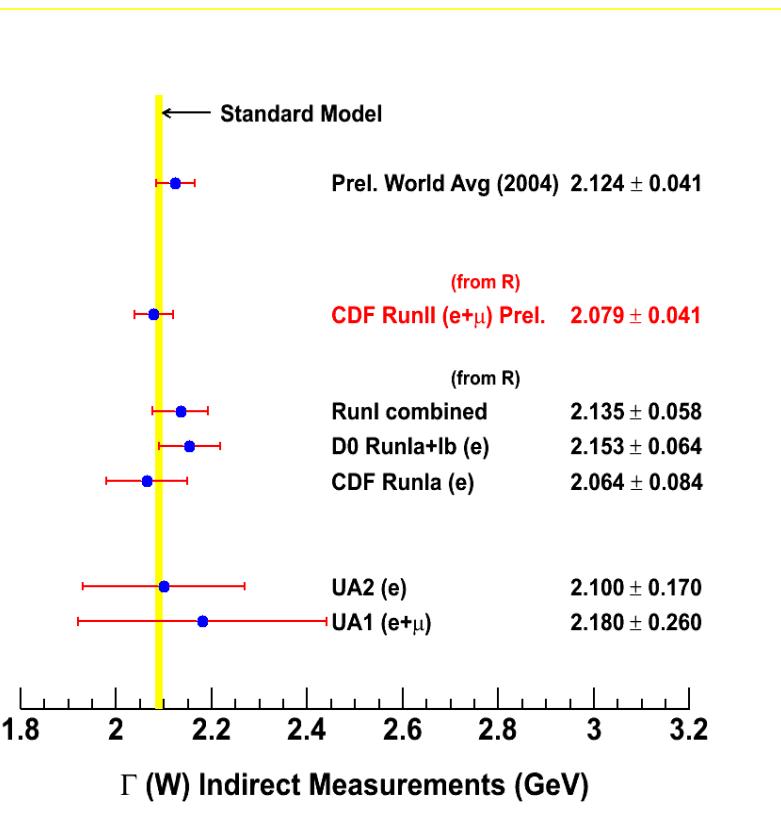
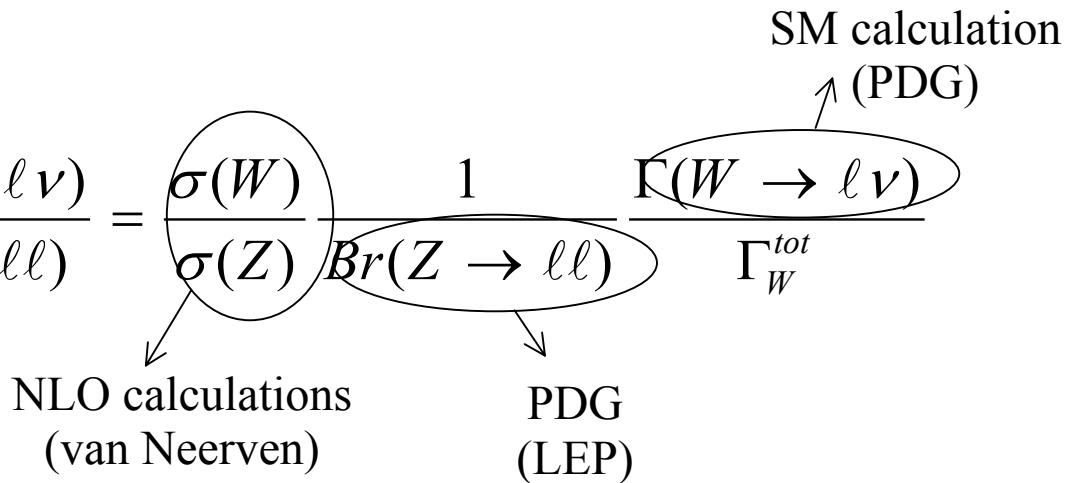


W, Z Cross Sections into Muon and Electron



$Z \rightarrow ee$	$255.8 \pm 3.9 \text{ (stat)} \pm 5.5 \text{ (sys)} \pm 15 \text{ (lumi) pb}$ (72 pb^{-1})	$264.9 \pm 3.9 \text{ (stat)} \pm 9.9 \text{ (sys)} \pm 17.2 \text{ (lumi) pb}$ (177 pb^{-1})
$Z \rightarrow \mu\mu$	$248 \pm 5.9 \text{ (stat)} \pm 7.6 \text{ (sys)} \pm 15 \text{ (lumi) pb}$ (72 pb^{-1})	$291.3 \pm 3.0 \text{ (stat)} \pm 6.9 \text{ (sys)} \pm 18.9 \text{ (lumi) pb}$ (148 pb^{-1})
$W \rightarrow e\nu$	$2780 \pm 14 \text{ (stat)} \pm 60 \text{ (sys)} \pm 166 \text{ (lumi) pb}$ $(\text{central, } 72 \text{ pb}^{-1})$ $2874 \pm 34 \text{ (stat)} \pm 167 \text{ (sys)} \pm 172 \text{ (lumi) pb}$ $(\text{plug, } 64 \text{ pb}^{-1})$	$2865 \pm 8.3 \text{ (stat)} \pm 76 \text{ (sys)} \pm 186 \text{ (lumi) pb}$ (177 pb^{-1})
$W \rightarrow \mu\nu$	$2768 \pm 16 \text{ (stat)} \pm 64 \text{ (sys)} \pm 166 \text{ (lumi) pb}$ (72 pb^{-1})	$2989 \pm 15 \text{ (stat)} \pm 81 \text{ (sys)} \pm 194 \text{ (lumi) pb}$ (96 pb^{-1})

$$R = \frac{\sigma(p\bar{p} \rightarrow W) \times Br(W \rightarrow \ell\nu)}{\sigma(p\bar{p} \rightarrow Z) \times Br(Z \rightarrow \ell\ell)}$$



CDF (72 pb⁻¹):

$$R(e+\mu) = 10.92 \pm 0.15 \text{ (stat)} \pm 0.14 \text{ (sys)}$$

DØ (177 pb⁻¹) :

$$R(e) = 10.82 \pm 0.16 \text{ (stat)} \pm 0.28 \text{ (sys)}$$

CDF: $\Gamma_W = 2.079 \pm 0.041 \text{ GeV}$

World average: $\Gamma_W = 2.124 \pm 0.041 \text{ GeV}$

SM value: $\Gamma_W = 2.092 \pm 0.003 \text{ GeV}$



Drell-Yan Differential Cross Section



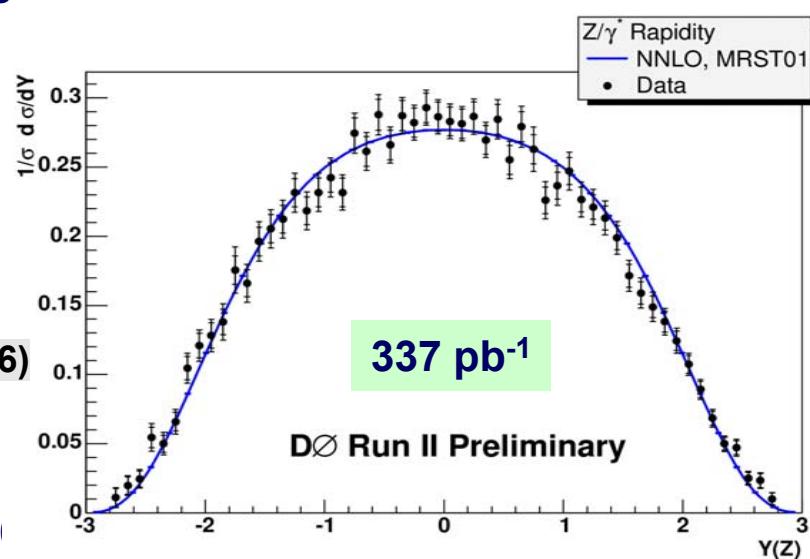
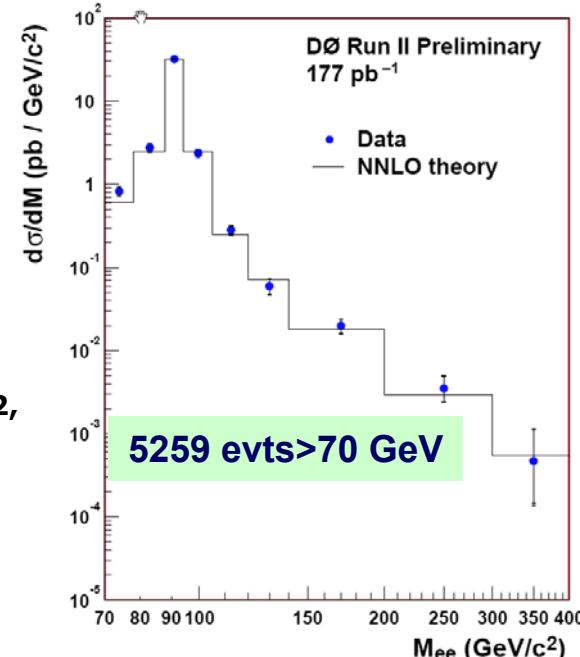
- Differential Drell-Yan cross section
 - Sensitive to new physics
 - Backgrounds (multijets with fake e id $\sim 1\%$)
 - Observe agreement with NNLO QCD calculations

$$\chi_{1,2} = \frac{M_Z}{\sqrt{S}} e_{\pm Y}$$

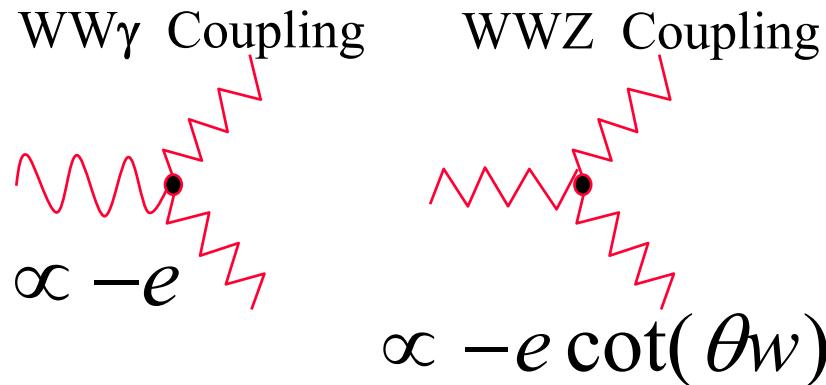
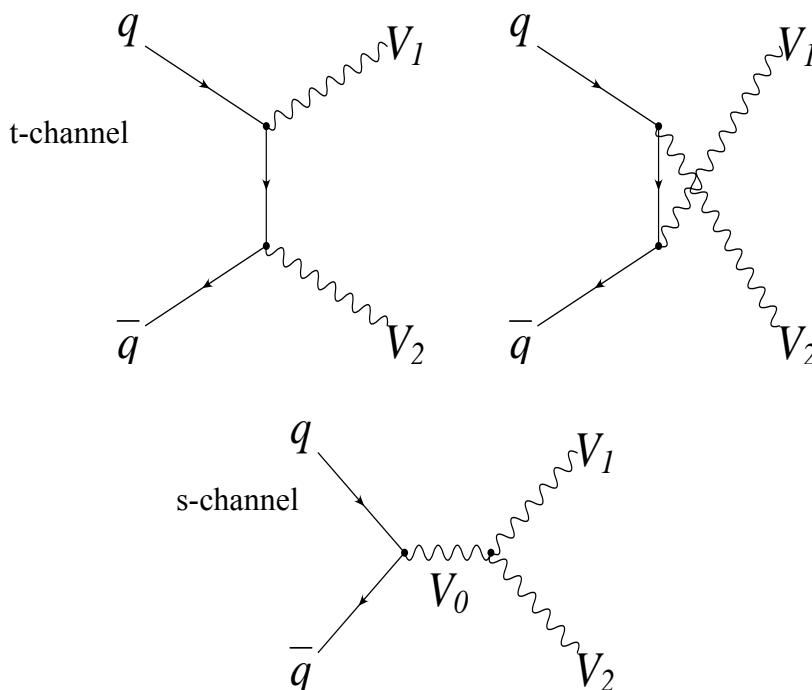
* $O(\alpha_s^2)$ calculation:
Hamberg, van Neerven and Matsuura,
Nucl. Phys. B 359, 343 (1991);
van Neerven and Zijlstra, Nucl. Phys. B 382, 11 (1992)

- Rapidity distribution
 - initial $q \bar{q}$ with $\Delta x \neq 0$ boosts boson
 - large $|Y|$ probes quarks low x (~ 0.001) and high Q^2 ($\sim M_Z^2$)
 - different systematics than jet data
- makes use of wide $|\eta|$ coverage of DØ calorimeter

*NNLO Curve from Anastasiou, et. al., 2004 (hep-ph/0312266)



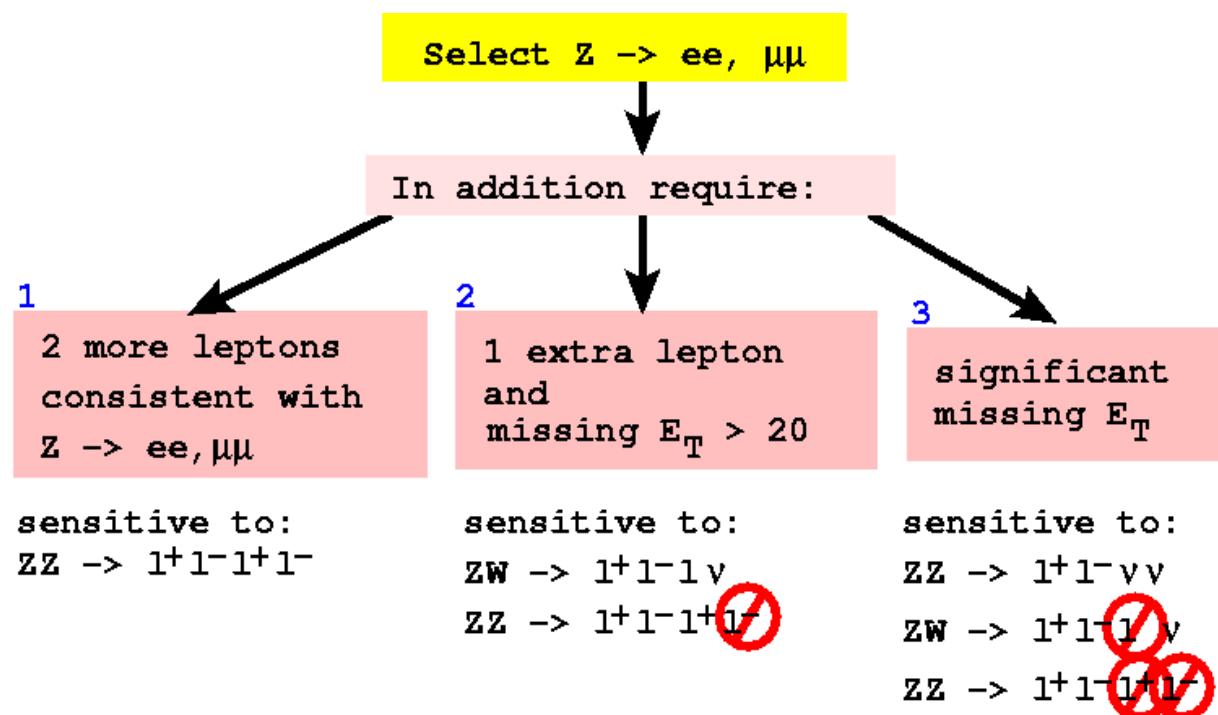
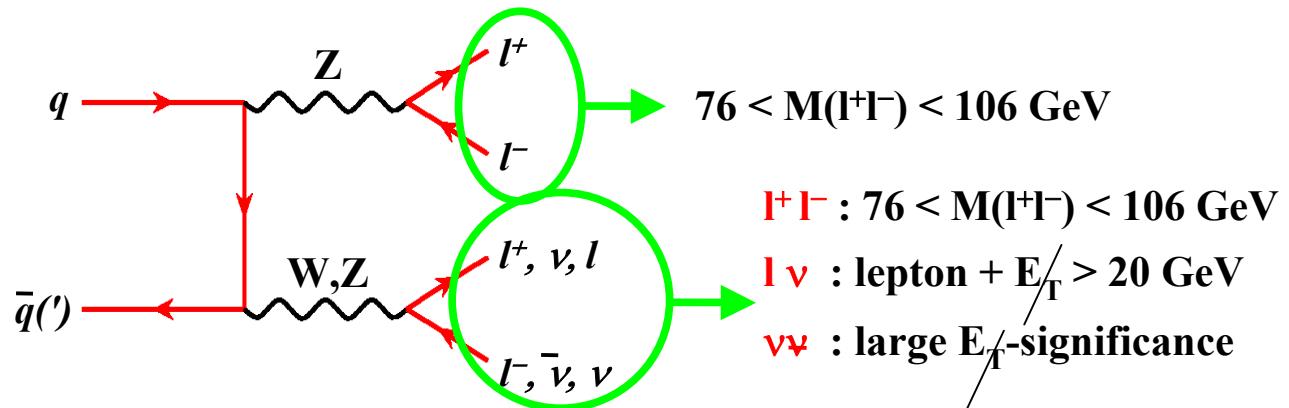
- Self-interactions are direct consequence of the non-Abelian $SU(2)_L \times U(1)_Y$ gauge symmetry. SM specific predictions.



- Cancellation of t- and u-channel by s-channel amplitude removes tree-level unitarity violation (in $W\gamma$, WW , and WZ , too).
 - **t-channel:** at high energy limit and with massless quarks (simpler calculation). σ violates unitarity.
 - **s-channel:** term of opposite sign cancels unitarity violating part.

$$\sigma(W_+W_-) \propto \frac{G_F^2 S}{3\pi}$$

@CDF





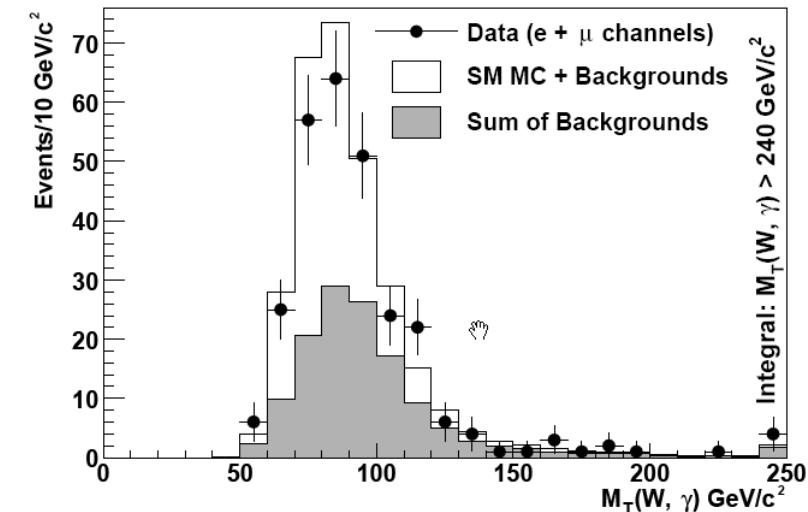
$W\gamma$ Production



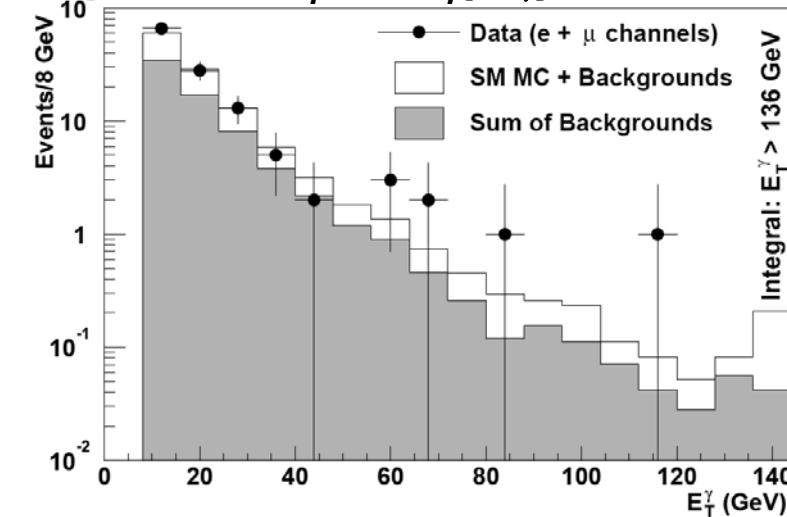
- Event selection $\int L dt = 162 (e), 134(\mu) \text{ pb}^{-1}$
 - High p_T electron or muon
 - Missing $E_T > 25, 20 \text{ GeV}$
 - Isolated photon with
 - $E_T > 8 \text{ GeV}, |\eta| < 1.1$
 - $\Delta R(l\gamma) > 0.7$
- Background estimation
 - $W + \text{jet}$ events from data
 - Probability for a jet to be misidentified as a photon
 - Estimated from multijet events in data
- SM predictions: Baur and Berger MC generator + parametrized detector simulation

Channel	e	μ
N_{obs}	112	161
N_{bkg}	60.8 ± 4.5	71.3 ± 5.2
$N_{obs} - N_{bkg}$	51.2 ± 11.5	89.7 ± 13.7

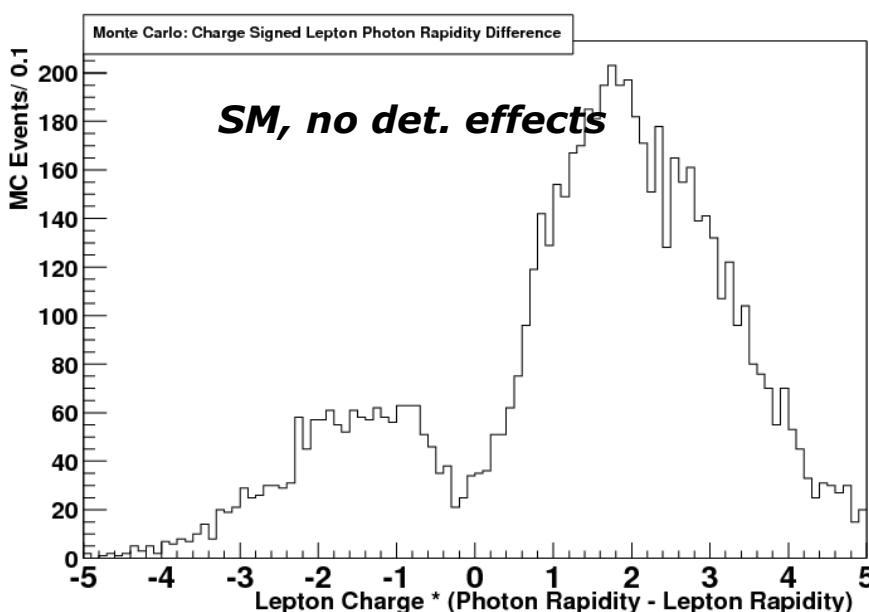
Transverse Mass ($W\gamma$)
DØ Run II



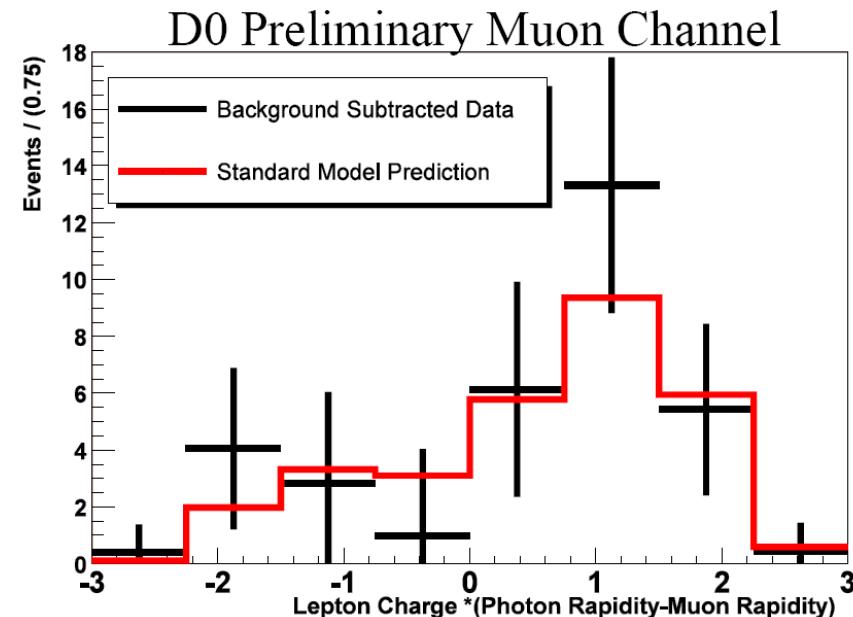
Photon E_T for $M_T(W\gamma) > 90 \text{ GeV}$



- Radiation zero in all helicity amplitudes for W γ production in SM
 - For $u\bar{d} \rightarrow W^+,\gamma$ amplitudes vanish for $\cos\theta = -1/3$
 - θ = scattering angle of photon w.r.t. quark direction in W γ rest frame
 - Corresponds to dip at $\eta(\gamma) - \eta(l^+) \approx -0.4$

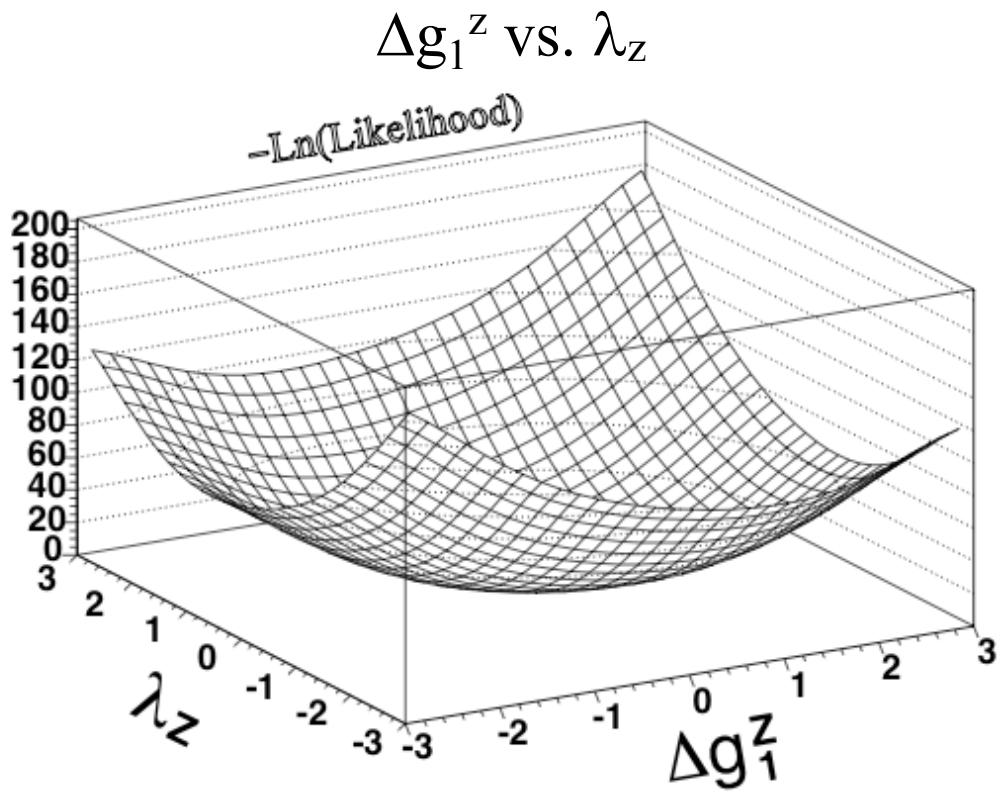


- In practice, zero is partially filled in
 - Effects of pdf's, higher-order QCD corrections, final state photon radiation



- Wide η coverage essential; extend for electrons and photons in future

- Generate a grid in coupling space using Hagiwara-Zeppenfeld-Woodside event generator.
 - K. Hagiwara, et al., Phys Rev. D **41**, 2113 (1990).
- Simulate the detector response using a fast Monte Carlo program.
- Calculate the Log likelihood at each point giving a surface.
- Find the 1-D & 2-D C.L.



$$L_{95\% \text{C.L.}} = L_{\min} + \delta$$

$\delta = 3.0 \text{ for 2-D, \& } 1.92 \text{ for 1-D}$



W γ cross section

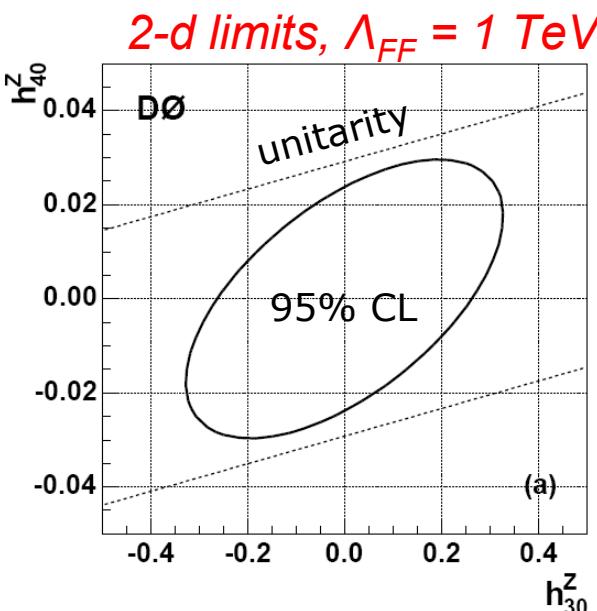
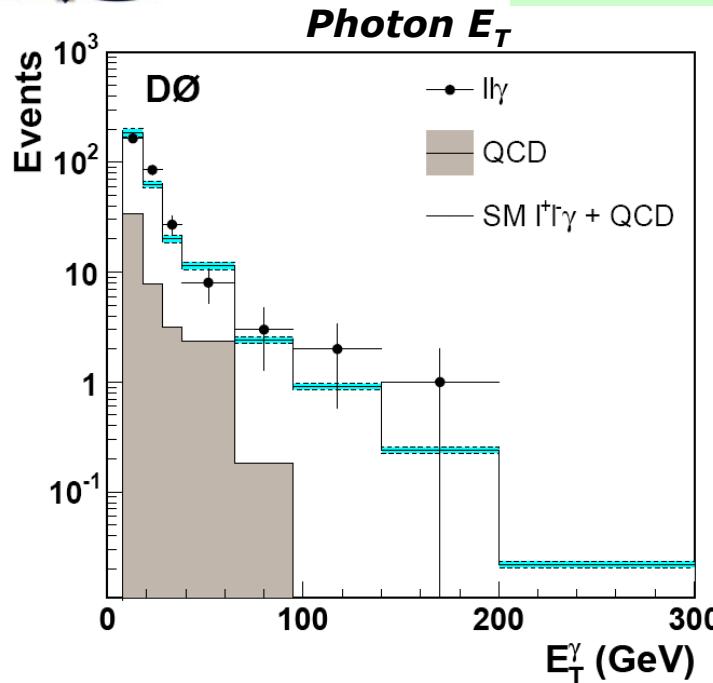


	$\sigma(pp \rightarrow W\gamma)$	SM, pb * expectation	E_T^γ
CDF	$18.1 \pm 1.6_{\text{STAT}} \pm 2.4_{\text{SYST}} \pm 1.2_{\text{LUM}}$	19.3 ± 1.4	7
DØ	$14.8 \pm 1.6_{\text{STAT}} \pm 1.0_{\text{SYST}} \pm 1.0_{\text{LUM}}$	16.0 ± 0.4	8

hep-ex/0410008

* Baur, Han, Ohnemus, 93/98

Both experiments quote cross section integrated over the acceptance



LEP

$$-0.056 < h_{10}^\gamma < 0.055$$

$$-0.045 < h_{20}^\gamma < 0.025$$

$$-0.049 < h_{30}^\gamma < 0.008$$

$$-0.002 < h_{40}^\gamma < 0.034$$

Tevatron/D \emptyset

$$-0.23 < h_{30}^\gamma < 0.23$$

$$-0.019 < h_{40}^\gamma < 0.019$$

$$-0.13 < h_{10}^Z < 0.13$$

$$-0.078 < h_{20}^Z < 0.071$$

$$-0.20 < h_{30}^Z < 0.07$$

$$-0.05 < h_{40}^Z < 0.12$$

$$-0.23 < h_{30}^Z < 0.23$$

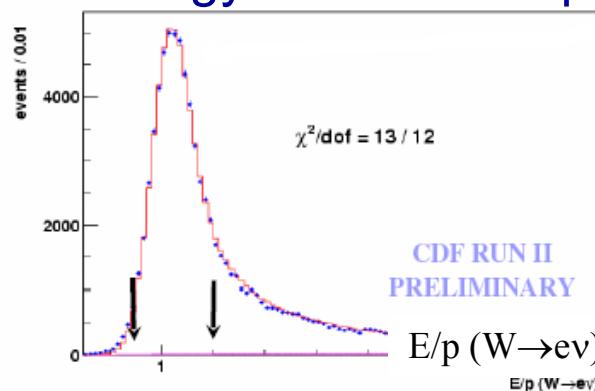
$$-0.020 < h_{40}^Z < 0.020$$

DØ : precision calorimeter calibration and data sample reprocessing

CDF: 200 pb^{-1} $W \rightarrow e/\mu$ “blind” mass analysis uncertainties determined:

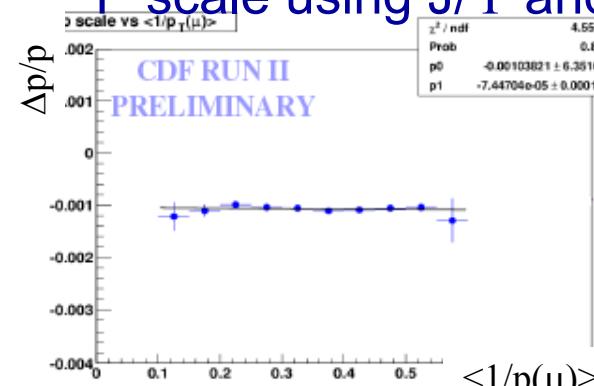
Electron channel

Energy scale with E/p



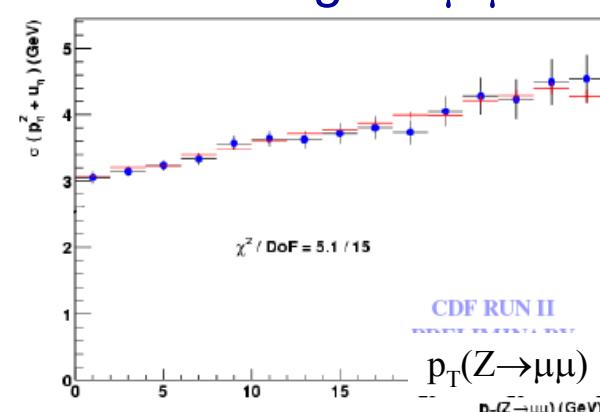
Muon channel

P scale using J/Ψ and Υ



Recoil model

tuned using $Z \rightarrow \mu\mu$



Systematic uncertainties in MeV (CDF)

	e	μ
Lepton energy scale and resolution	70	30
Recoil scale and resolution	50	50
Statistics	45	50
Production and decay model	30	30
Background	20	20

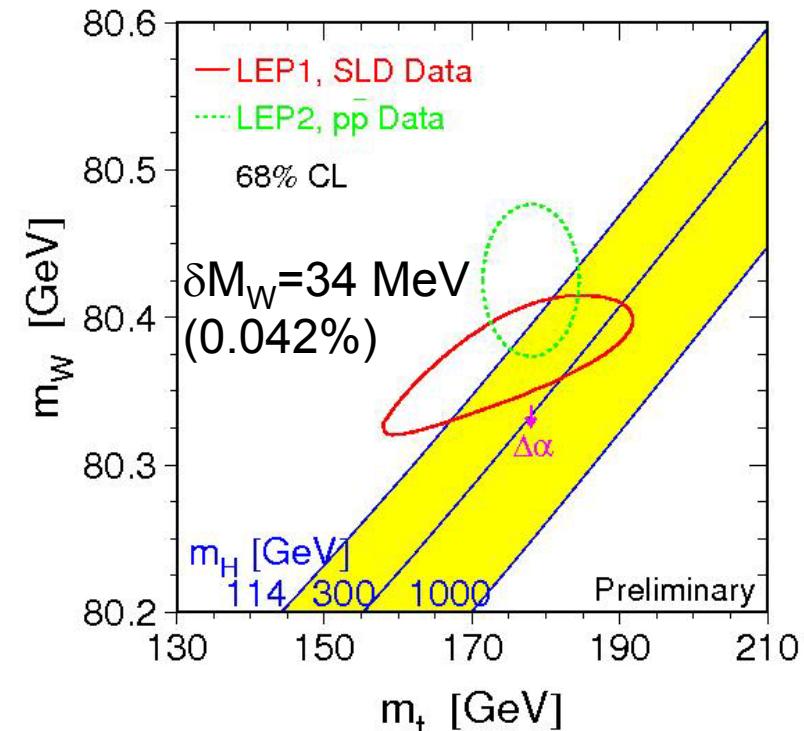
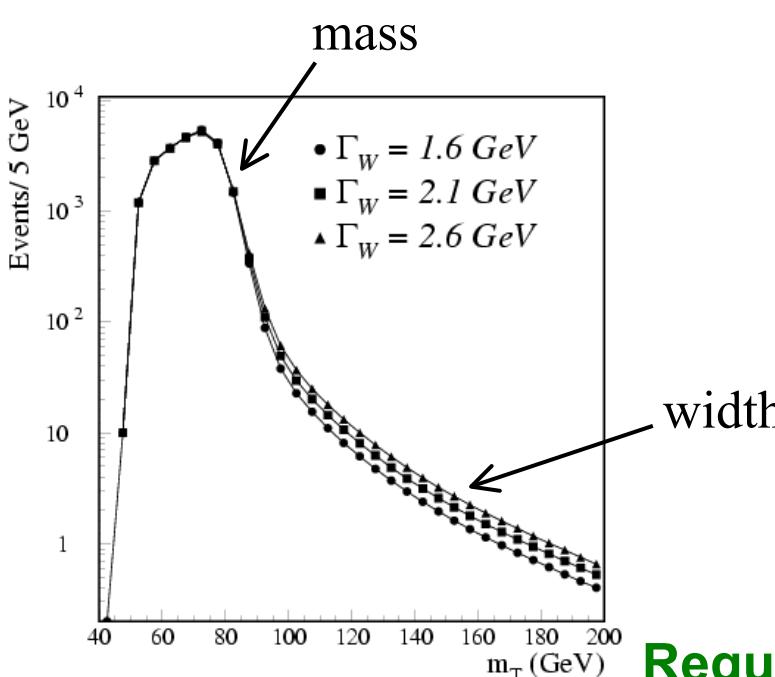
Total: 76 MeV (Run I: 79 MeV)

SM predicts M_W in terms of Z , t masses and EW coupling

$$M_W^2 = \frac{\pi \alpha(M_Z^2)}{\sqrt{2} G_F} \frac{1}{(1 - (M_W^2/M_Z^2))} \frac{1}{(1 - \Delta r)}$$

to 0.014% at $Q^2 = M_Z^2$

Radiative corrections (top/Higgs)
0.67% correction



Require the best knowledge of the detectors